Pound, Vivian Ellsworth

1. The Absorption of the different types of beta rays together with a study of the secondary rays excited by them.

2. On the secondary rays excited by the alpha rays from polonium. Parts 1 and 2.

# I. The Absorption of the Different Types of Beta Rays together with a Study of the Secondary Rays excited by them.

# II. On the Secondary Rays excited by the Alpha Rays from Polonium. Part I.

# On the Secondary Rays excited by the Alpha Rays from Polonium. Part II.

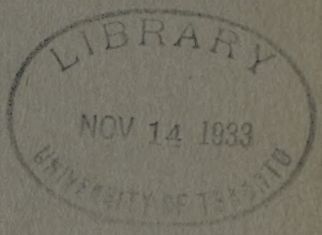
## A THESIS

Presented to the Senate of the University of Toronto for the Degree of

DOCTOR OF PHILOSOPHY

BY

VIVIAN ELLSWORTH POUND.

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To the Senate of the University of Toronto:

Gentlemen:

I beg to recommend that the Thesis entitled:—

"I. The Absorption of the Different Types of Beta Rays together with a Study of the Secondary Rays excited by them.

II. On the Secondary Rays excited by the Alpha Rays from Polonium. Part I.

On the Secondary Rays excited by the Alpha Rays from Polonium. Part II."

submitted by Mr. Vivian Ellsworth Pound, be accepted for the Degree of Doctor of Philosophy. I certify that "it is a distinct contribution to the knowledge of the subject of which it treats".

(Signed) J. C. McLennan,
*Professor of Physics.*

*March 28th, 1912.*

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I hereby certify that the Thesis above mentioned has been accepted by the Senate of the University of Toronto for the Degree of Doctor of Philosophy in accordance with the terms of the Statute in that behalf.

(Signed) James Brebner,
*Registrar.*

University of Toronto,
*May 30th, 1913.*

## VI.—*The Absorption of the Different Types of Beta Rays together with a Study of the Secondary Rays Excited by them.*

By V. E. POUND, M.A., University of Toronto.

(Communicated by Prof. J. C. McLennan and read May 26, 1908.)

I. INTRODUCTION. In a paper in the Phil. Mag., of July, 1907, Prof. MacKenzie gives an account of some observations which he made on the secondary radiation issuing from each side of plates of lead upon which a pencil of $\beta$ rays was allowed to fall. Using plates of increasing thickness, he found that the secondary radiation issuing from the side of the plate upon which the $\beta$ rays fell, gradually increased in intensity and reached a maximum value when a plate .2 mms. in thickness was used. With plates of still greater thickness, this secondary radiation remained constant in intensity. He obtained, however, an entirely different result on investigating the secondary radiation from the back of the plate upon which the $\beta$ radiation was allowed to fall. Under these conditions the secondary radiation fell off very slowly as the thickness of the plates increased, and was still quite measurable with plates of lead 15 mms. in thickness.

In arriving at these results, MacKenzie[1] investigated the secondary radiation issuing from each side of the plates, first, when both $\beta$ and $\gamma$ rays were allowed to fall on them, and second, when $\gamma$ rays alone were allowed to fall on the plates, and the results quoted by him, and ascribed by him to the action of the $\beta$ rays were obtained by subtracting the effects due to the $\gamma$ rays alone from those due to the combined $\beta$ and $\gamma$ radiations.

With the arrangement he adopted it was possible that in cutting off the $\beta$ rays in order to study the effect of the $\gamma$ radiation alone he also cut off a greater proportion of the latter than he estimated. If this were so it would result in ascribing to the $\beta$ radiation a part of the secondary radiation. which properly should have been ascribed to the $\gamma$ rays.

In view of the importance of his results in their relation to theories of secondary radiation now being put forward by Bragg[2] and others, it was thought well to make a more extended examination of the secondary radiations excited by both $\beta$ and by $\gamma$ rays, and in the following paper an account is given of some experiments in which the secondary radiation both from the back and the front of metal plates was studied, when these were traversed by $\gamma$ rays alone, and also when pencils of $\beta$ rays of different types were allowed to fall on them.

[1] Phil. Mag., July 1907.
[2] Phil. Mag., May 1908.

In differentiating the effects due to the various types of rays, the action of each was ascertained by deflecting pencils of each type into an ionisation chamber away from the others by means of a magnetic field.

II. Apparatus:—The arrangement adopted is shewn in Fig. I. The receptacle for holding the radium was a lead cylinder A with walls 4 cm. thick. One end of the cylinder was covered by a brass plate 2.5 mms. thick, in the centre of which was a hole 4.5. mms. in diameter. The capsule holding the radium was held close against this plate in such a position that the rays from the radium on issuing, passed between the poles of a powerful electromagnet. Immediately beneath the pole pieces of the electromagnet was the ionisation chamber B. It also was made of lead in the form of a cylinder 6.7 cms. long, with walls 4.6 cms. in thickness, the ionisation chamber proper being 4.7 cms. in diameter. At the top and bottom were brass rings to hold different thicknesses of selected absorbing materials over the ends of the chamber.

A properly screened and insulated electrode was inserted into the ionising chamber and connected to a Dolezeleck electrometer by means of which saturation currents were measured. The sensibility of the electrometer was such that a potential difference of one volt between the quadrants produced a deflection of 625 mms. on a scale about one metre distant from the needle. It was found that a potential of 240 volts applied to the ionisation chamber was always amply sufficient to give the saturation current.

III. Experiments on the Absorption and Reflection of $\beta$ rays by tinfoil.

A. Measurements on transmitted rays.

In these experiments the $\beta$ rays from the radium, on coming between the poles of the magnet, were deflected either downwards or upwards according to the direction of the field between the poles. As the capsule containing the radium was covered by a thin sheet of mica, the $\alpha$ rays were largely absorbed, so that the issuing beam contained only $\beta$ and $\gamma$ rays, which could easily be separated by the magnetic field in the manner indicated. Readings were taken of the saturation currents in the ionisation chamber as the current through the electromagnet was changed by small increments from 0 to about 28 amperes.

A series of measurements was made with a number of different thicknesses of absorbing layers of tin foil over the top of the ionisation chamber, and with the bottom of the chamber closed by a thin sheet of aluminium foil, .0065 mms. in thickness.

Before making these, however, a set of readings was taken with-

out any metallic covering over the opening at the top of the ionising chamber, and with only the single sheet of aluminium foil over the opening at the bottom. In taking these the magnetic field was first applied in such a direction as to deflect the $\beta$ rays down into the chamber and observations were made on the saturation currents corresponding to various field strengths. The field was then reversed and a second set of readings taken as the $\beta$ rays were gradually deflected upwards and away from the chamber. Both sets of readings are given in column I of Tables I and II and curves representing them are shown in Fig. 2. From these curves it is seen that as the $\beta$ rays were deflected down into the chamber by the magnetic field, the ionisation in the chamber rapidly increased to a maximum value and then decreased as the different pencils of rays were swept past by the increasing magnetic field. It is seen, also, that when the $\beta$ rays were deflected upwards and away from the chamber by gradually increasing magnetic fields the corresponding saturation currents decreased rapidly until a constant limiting value was reached.

As already stated similar sets of readings were taken for different thicknesses of absorbing layers of tin foil over the top of the chamber. In columns II to V of Tables I and II are given the results obtained with layers .0196 mms., .0784 mms., .1568 mms., and .3136 mms. in thickness respectively and curves A, B, C, and D, corresponding to the results given in columns II to V of Table I are shown in Fig. 3.

Here again, it will be seen, when the $\beta$ rays were deflected downwards that with each absorbing layer the saturation current passed through a maximum value. It will be seen, too, that the maximum saturation current fell away as the absorbing layer was increased, and further that as the thickness of the layers was increased it required a stronger and stronger field to produce the maximum ionisation.

The explanation of these results is found in the fact that the $\beta$ rays issued from the radium in a number of approximately homogeneous sheaves or pencils possessing a maximum intensity in a direction at right angles to the axis of the ionising chamber. On applying the magnetic fields these sheaves or pencils would undergo different degrees of deflection, those of high velocity being less affected by the field than the more slowly moving ones.

As the rays from a sheaf of low velocity would enter the chamber first, the ionisation would increase and reach a maximum when the axis of this sheaf of rays coincided with the axis of the ionising chamber. Still higher fields would deflect the slow moving rays past the opening of the ionising chamber and introduce others possessing still higher velocities. In as much as Bragg,[1] and others, have shown that the

[1] Phil. Mag., Oct. 1907.

ionising power of $\beta$ rays of high velocity is not so great as that of those moving more slowly, it follows that with increasing magnetic fields the ionising power of the rays introduced would be less than that of the rays cut out and hence a drop in the ionisation values would occur. This drop in the conductivity would continue until ultimately all the deflectable $\beta$ rays were swept past the chamber. As the layers of tinfoil were gradually increased in thickness the more slowly moving $\beta$ rays would be absorbed and the first effective sheaves transmitted would consist of rays possessing higher and higher penetrability and consequently of rays with less and less ionising power. It follows then that while a maximum conductivity would be obtained with each thickness of tin foil the value of the maximum would decrease with the thickness of the absorbing layer. It is evident, too, since with increasing thicknesses the first effective sheaves of transmitted rays would possess higher and higher velocities, that the field required to deflect the axis of these different sheaves into coincidence with the axis of the chamber would increase. Hence the maximum conductivities, when absorbing layers of increasing thicknesses were used would be obtained by fields excited by currents of greater intensity, and this, as the curves A, B, C, and D shew, is actually what happened.

The numbers corresponding to the saturation currents obtained with the different absorbing layers when the rays were deflected upwards and away from the chamber by the magnetic fields are given in columns II to V of Table II, and curves representing them are shewn in Fig. 4. From these it will be seen that with each absorbing layer the ionisation fell away as the rays were deflected upwards and soon reached a value which was constant, and which represented the natural conductivity of the air in the chamber together with that impressed upon it by the undeviable rays from the radium and by the secondary rays which they excited.

These limiting curves it will be seen exhibit an effect already pointed out and emphasized by MacKenzie[1] and others, that when the thickness of a plate or wall upon which $\gamma$ rays are allowed to fall is gradually increased the gain in ionisation at the back of the plate from the secondary radiation is at first greater than the loss produced by the absorption of the primary rays. This result is well exemplified by the curves A′, B′, C′, and D′, which correspond to absorbing layers of increasing thickness and which shew that the limiting value of the ordinate of B′ is greater than A′, that of C′ is equal to that of B′, and that of D′ is again less than that of C′.

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[1] MacKenzie, Phil. Mag., July, 1907.

In addition to the measurements just described, others were taken for magnetic fields in both directions with absorbing layers 1.234 mms., 1.96 mms., and 3.136 mms. in thickness, and the results of these are recorded in Tables I and II. The curves E, F, and G, Fig. 5, were plotted from the numbers in columns VI to VIII of Table I and represent the conductivities obtained with fields which deflected the $\beta$ rays down towards the chamber. The numbers corresponding to the saturation currents obtained with different absorbing layers when the rays were deflected upwards and away from the chamber are given in columns VI to VIII of Table II, and curves E′, F′, and G, which were drawn from the numbers given in this table are shewn in Fig. 5. and represent the conductivities when the rays were deflected in the opposite direction.

The short sharp rise in the curve E shews that with tinfoil 1.254 mms. in thickness the $\beta$ rays were still able to penetrate the absorbing layer. A slight rise, as can be seen from the figure occurs in the Curve F, but with the Curve G no evidence exists of any rise in conductivity. This curve, moreover, coincides with the Curve G′ which is drawn from values of the ionisation obtained when the rays were deflected upwards, and this coincidence of the two curves G and G′ shews that with the absorbing layer with which the results illustrated by these curves were obtained, a thickness of tinfoil was finally reached which could not be penetrated by the $\beta$ rays and by the secondary rays which were produced by them in the metal.

In order to find the precise thickness of tinfoil necessary to stop all the $\beta$ and $\beta$ secondary radiations, a curve shewn in Fig. 6 was plotted taking as ordinates the ionisation in the chamber due to the maximum $\beta$ and $\beta$ secondary rays for each thickness of tinfoil, and as abscissæ the thickness of the tinfoil screen with which each maximum was obtained. The maximum $\beta$ and $\beta$ secondary ionisation for each thickness was determined in the following manner. Taking the results for a particular thickness, the limiting value of the ordinate of the curve drawn for a deflection of the $\beta$ rays upwards was subtracted from the maximum value of the ordinates of the curve drawn for deflections of the $\beta$ rays downwards. Inasmuch as the limiting value of the ordinates of the former curve represented the ionisation in the chamber due to $\gamma$ rays, and $\gamma$ secondary, together with that due to natural causes, and the maximum value of the ordinates of the latter, the ionisation due to the maximum $\beta$, $\beta$ secondary, $\gamma$ and $\gamma$ secondary radiations with that due to natural causes, the difference gave the ionisation due to the maximum $\beta$ and $\beta$ secondary ionisation for the particular thickness of tinfoil over the top of the ionisation chamber.

In Table III there is collected and given in row I, the maximum saturation currents in the chamber due to the $\beta$, $\beta$ secondary, $\gamma$ and $\gamma$ secondary radiations and that due to natural causes, for the screens of different thicknesses of tinfoil; in row II, the saturation currents due to the $\gamma$, and $\gamma$ secondary radiations and that due to natural causes, and in row III, the deduced maximum ionisation due to the $\beta$ and $\beta$ secondary radiations for the same screens of tinfoil sheets.

The ordinates of the curves in Fig. 6, are the values of the maximum $\beta$ and $\beta$ secondary ionisations taken from row III of the above table. The curve, as will be seen, is drawn with an initial rise, although no values were obtained from which the position of the highest point could be determined. Some observations to be given later, however, on the determination of the maximum thickness of aluminium necessary to absorb all the $\beta$ and $\beta$ secondary radiations, shew clearly that for aluminium the ionisation in the chamber due to the $\beta$ rays rose and fell as the thickness of aluminium was increased. The inference was therefore drawn that for all metals this rise and fall in the conductivity due to $\beta$ rays striking a wall of the chamber would occur, and would be made manifest if thin enough sheets of the metal were used.

From the regular manner in which the curve in Fig. 6 falls away, it is clear that in the experiments with tinfoil the thickest screen used was amply sufficient to absorb all the $\beta$ rays and the secondary rays excited by them. An examination of the curve, moreover, makes it evident that even a thickness of 2.5 millimetres of tinfoil was amply sufficient for that purpose.

B. Measurements on reflected rays.

A series of measurements was also made on the secondary radiation produced at the front side of sheets of tinfoil when $\beta$ and $\gamma$ rays were allowed to fall on them. One layer of aluminium foil .0065 mms. in thickness was placed over the opening at the top of the chamber. and layers of tinfoil of increasing thickness were placed over the opening at the bottom. In these experiments the capsule containing the radium bromide was placed vertically above the ionisation chamber, so that the rays after passing between the poles of the magnet impinged directly on the thin sheet of aluminium foil forming the upper wall of the ionisation chamber, and after passing through it, traversed the air in the chamber and then impinged on the tinfoil at the bottom. As the magnet was excited by increasing currents the $\beta$ rays were more and more deflected until all were swept aside by the field and $\gamma$ rays alone entered the chamber.

In column II of Table IV is given a typical set of these measurements, and a typical curve plotted from them is shewn in Fig. 7. The values obtained with the complete set of reflectors used are

recorded in Table IV, and it may be seen from the curve in Fig 7 that after a field corresponding to ten amperes was exceeded, the ionisation approached a limiting value which indicated that for magnetic fields excited by currents of ten amperes, and greater, the $\beta$ rays were all turned aside and the $\gamma$ rays alone were left to enter the chamber. The maximum ionisation due to the $\beta$, $\beta$ secondary, $\gamma$, $\gamma$ secondary, and that due to natural causes is given by the ordinate of the initial point of this curve. With the interpretation given above the ionisation due to the $\gamma$, $\gamma$ secondary, and that due to any radiations from the metal forming the walls of the chamber may be taken to be represented by the point on the curve corresponding to the highest field. The difference in the values of these two ionisations gives a value for the maximum conductivity impressed upon the air by the $\beta$ rays, and by the secondary radiations excited by them in the tinfoil.

In Table V is given the deduced values of the maximum ionisations which were due to $\beta$ and $\beta$ secondary rays from similar sets of measurements for different thicknesses of tinfoil at the bottom of the chamber. The curve drawn in Fig. 8 is plotted with ordinates representing the values of these maximum $\beta$ and $\beta$ secondary ionisations as recorded in the fourth column of this table, and with abscissæ representing the corresponding thicknesses of tinfoil. From this curve it is clear that the maximum conductivities produced by the $\beta$ and the reflected $\beta$ secondary rays reached a limiting value when the tinfoil sheets attained a thickness of .24 mms. and for still greater thicknesses remained constant.

Summarising all the results obtained with tinfoil it would then appear:—That when $\beta$ rays from radium are allowed to impinge on sheets of tinfoil a maximum reflected secondary radiation is obtained when the tinfoil attains a thickness of .24 mms., and further that a thickness of 2.5 mms. of tinfoil is sufficient to absorb not only the transmitted secondary rays excited by $\beta$ rays, but also the whole of the primary radiation itself.

This result, however, while giving definite information regarding a lower limit to the thickness of tinfoil requisite to absorb primary $\beta$ rays gives only an upper limit to the thickness necessary to absorb the transmitted secondary radiations produced by such rays. In order to obtain a lower limit to the thickness of tinfoil required to absorb the transmitted $\beta$ secondary radiation alone which is excited by $\beta$ rays, it would be necessary to modify considerably the arrangement of the apparatus used in making these measurements.

*IV. Experiments on the Absorption and Reflection of β Rays by Lead.*

A. Measurements on the transmitted rays.

Experiments were conducted with lead in an exactly similar manner to those on the transmitted rays through tin foil, in order to find the minimum thickness of lead necessary to prevent the emergence of any $\beta$ or $\beta$ secondary radiations from the far side of a plate upon which the primary $\beta$ rays of radium fell. The radium bromide was placed as in Fig. 1, and sets of readings were taken of the ionisation in the chamber,—1st, with the top of the chamber open, and, 2nd, with it covered by lead foil of varying thicknesses, the bottom of the chamber being always closed by a sheet of aluminium foil .0065 mms. in thickness. As before, these readings were taken as the $\beta$ rays were deflected downwards into the ionisation chamber, and upwards and away from it by different magnetic fields.

The sets of readings taken with the opening at the top of the chamber uncovered, and also covered with lead foil screens .241 mms., .482 mms., .723 mms., and .964 mms., in thickness, respectively, are given in Tables VI and VII. From the values of the ionisations given in columns III, IV and V of Table VI, the curves A, B, and C, Fig. 9, were drawn. The curves A′, B′, and C also shewn in Fig. 9 were plotted from the numbers in columns III, IV and V of Table VII. The curves are of the same type as those for the tinfoil, which were fully discussed in Section II A.

The curve B drawn for a thickness of .723 mms. of lead indicates that $\beta$ rays which were deflected by a field corresponding to about 6 amperes penetrated this thickness of lead, while the coincidence of the curves C drawn from the values corresponding both to the upward and downward deflections of the $\beta$ rays when .964 mms. was the thickness of the lead screen, shews clearly that the $\beta$ and also the $\beta$ secondary rays could not pass through this thickness of lead.

As is fully explained in Section III A, the maximum value of the conductivities in the chamber due to $\beta$ and $\beta$ secondary rays for the different thicknesses of the screens can readily be deduced from the tables given above. These deduced values are given in row III of Table VIII, and a curve representing them is shewn in Fig. 10. From the curve it is evident that a screen of lead .9 mms. in thickness completely absorbed all of the $\beta$ and the $\beta$ secondary radiations excited in the lead including the most penetrating.

B. Measurements on reflected rays from lead.

In this set of measurements the arrangement of the apparatus was the same as when the measurements on the reflected rays from tin were taken, the radium being placed vertically above the ionisation chamber. Different thicknesses of lead were placed over the opening

at the bottom, while the single sheet of aluminium foil .0065 mms. in thickness covered the top. As before, the saturation currents in the chamber were taken as the magnetic field deflected the $\beta$ rays farther and farther from the opening of the chamber, and the values of the saturation currents are given in Table IX. From these it will be seen that with the lead reflectors of different thicknesses the saturation currents were practically the same when magnetic fields of sufficient strength to deflect all the $\beta$ rays were applied. In order to ascertain the maximum ionisation for the various lead reflectors due to the $\beta$ ray effect, the mean of the readings obtained with the high fields was taken as representing the conductivity due to the $\gamma$ radiations, that due to the secondary radiations excited by these in the reflectors, and also that due to the so-called natural ionisation. This mean was subtracted from the maximum ionisation obtained with each of the reflectors before the application of a magnetic field and the differences which are recorded in column IV of Table X, and represented graphically by the Curve A in Fig. 11 were taken to represent the ionisations produced in the chamber by the primary $\beta$ rays and by the secondary rays excited by them in the lead reflectors. From a consideration of those values and of the form of the curve in Fig. 11, it is evident that a maximum secondary radiation due to the impact of $\beta$ rays on the lead reflectors was obtained with a thickness of .16 mms. of this metal.

From these results then it is clear that the secondary radiation emitted by the front side of a lead plate, which the $\beta$ rays from radium fall do not come from a depth of the metal greater than .16 mms. It is also established by the results that a plate of lead .9 mms. in thickness will completely absorb all the primary $\beta$ rays from radium as well as all the secondary radiation excited by these rays in the lead plate.

### *V. Experiments on the Absorption and Reflection of $\beta$ Rays by Aluminium Foil.*

A. Measurements on transmitted rays.

A series of readings was also made with a number of different thicknesses of absorbing layers of aluminium foil over the top of the chamber, in order to find the minimum thickness of aluminium necessary to stop the $\beta$ rays. The bottom of the chamber was closed by the same sheet of aluminium foil .0065 mms. thick, used throughout these experiments. As before, the first series of measurements was taken without any cover over the top of the chamber and this series is given in column I of Tables XI and XII. The results obtained with layers .0065, .28 mms., 1.184 mms., 3.41 mms., 4.73 mms., and

8.14 mms., in thickness respectively are given in columns II to VII of Tables XI and XII.

The curves A, B, C, D, and E, shewn in Figs. 12 and 13 are plotted from the results given in columns I, II, IV, VI and VII of Table XI, and curves D′ and E′, Fig. 13, from the results given in columns VI and VII of Table XII.

On comparing the results obtained when there was no metallic covering over the opening at the top of the ionisation chamber with the results when a covering of .0065 mms. of aluminium was used, it is readily seen that the addition of the covering considerably increased the maximum ionisation in the chamber as the $\beta$ rays were deflected into it. This effect is also brought out very clearly by the curves A and B in Fig. 12. This increase in ionisation in the chamber due to the thin covering of aluminium was interpreted as being due to the action of secondary radiation. The small thickness of aluminium foil used would only absorb a very small proportion of the primary $\beta$ rays, and, consequently, it would be possible for the excited secondary rays to make a contribution to the ionisation in the chamber greater than the loss incurred by the absorption of the primary rays. Of course, it is also possible that the increase in ionisation observed could be interpreted as being due to a decrease in velocity impressed upon the primary rays by their passage through the foil. It is to be noted, too, in connection with this explanation, that since the values of the ionisation shewn by curve A were obtained with the opening at the top of the chamber uncovered, these undoubtedly represented the ionisation of a somewhat larger body of air than was used in the experiments when the opening was covered. It follows, therefore, that the real increase in ionisation produced by the passage of the $\beta$ rays through the single sheet of aluminium should have been greater than that indicated by the curves A and B of Fig. 12. Some measurements were made with screens of two and of three sheets of aluminium, and as these were found to give maximum ionisations approximately the same as that obtained with a single sheet, it was seen that in order to investigate more fully this rise in conductivity it would be necessary to use still thinner sheets of aluminium than the one with which the opening was first closed. As this point was not specially pertinent to the subject under investigation by the writer, its examination was deferred. This rise in conductivity resulting from the passage of $\beta$ rays through a thin layer of aluminium was not observed in the experiments with lead and tin screens, doubtless because the least thicknesses of these metals absorbed more of the primary $\beta$ rays than could be compensated for by the excited secondary radiations. This result, it will be remembered, was referred to in Section

III A, and was given as a reason for drawing the curve shewn in Fig. 6 with an additional rise, although no determinations were made with which it could be confirmed.

Curve C shews that while the more deflectable of the $\beta$ radiations were absorbed by 1.184 mms. of aluminium foil, the more penetrating still passed through it. The slight rise in curve D also indicates that some of the $\beta$ radiation was still able to penetrate 4.73 mms. of aluminium. With a thickness of 8.14 mms. of aluminium, however, no rise in the conductivity occurred, and as curve E, Fig. 13 shews, this thickness was sufficient to cut off all the $\beta$ ray effect.

It will be seen that the curves which are drawn on a large scale for deflections of $\beta$ rays downwards, and for deflections of these rays upwards, corresponding to a thickness of 8.14 mms. of aluminium over the opening at the top of the chamber and denoted by E and E′ do not coincide. It will be recalled further, that the curves drawn for the limiting thicknesses of tin and lead under the same conditions shewed an exact coincidence. This peculiarity in the behaviour of the aluminium screen was investigated at considerable length and was finally shewn by some experiments which are described later in Section VI to be due to the action of the secondary $\beta$ rays excited on the far side of the thicker aluminium screens by the $\gamma$ rays entering the chamber.

In Table XIII there is given in row I the maximum saturation currents in the chamber due to the $\beta$, $\beta$ secondary, $\gamma$ and $\gamma$ secondary radiations and that due to natural causes for the different thicknesses of aluminium foil, in row II, the saturation currents due to the $\gamma$ and secondary radiation and that due to natural causes and in row III, the maximum ionisations due to the $\beta$ and $\beta$ secondary radiations deduced as explained in Section III A, from the Tables above and their corresponding curves. On looking at the figures given in row III of this table, it is seen that there is apparently a $\beta$ ray ionisation of .5 or about one-seventh of one per cent of the greatest $\beta$ ray ionisation in the chamber when the top of the chamber is covered by 8.14 mms. of aluminium. This conductivity, however, represents really a $\gamma$ ray effect, due as said before to the thickness of the aluminium used and should be deducted from the last three of the numbers given in row III of the table. These corrected values of the maximum $\beta$ and $\beta$ secondary ionisations are given in row IV, and a curve, Fig. 14, is plotted from these values. An examination of this curve makes it evident that a thickness of approximately 7 mms. of aluminium foil was amply sufficient to absorb all the $\beta$ rays, and the secondary rays excited by them.

B.—Measurements on reflected rays from aluminium.

A series of measurements was also made on the secondary radiation produced at the front side of sheets of aluminium foil when $\beta$ and $\beta$ rays were allowed to fall on them, and from these the critical depth of the $\beta$ ray effect has been determined. The arrangement of the apparatus was the same as for the measurements on the reflected radiations from tin and lead. The values of the saturation currents in the chamber found for the different thicknesses of aluminium foil at the bottom are given in Table XIV, and the maximum ionisations due to the $\beta$ rays have been deduced from these tables and their corresponding curves. These maximum currents are given in Table XV and the curve in Fig. 15 plotted from them shews the manner in which the intensity of the secondary radiation was increased. From this curve it is evident that the maximum conductivity produced by the $\beta$ and the reflected $\beta$ secondary rays attained a limiting value when the aluminium foil sheets reached a thickness of .4 mms.

It follows then from these results that a thickness of 7 mms. of aluminium will completely absorb all the $\beta$ rays from radium and the secondary rays which they excite in the metal. It follows too that the secondary rays, emitted by the front side of a plate of the metal when bombarded by the $\beta$ rays from radium do not come from a depth in the metal greater than .4 mms.

*VI.—Experiments on the Secondary Rays Excited in Aluminium by $\gamma$ Rays.*

It has been stated in Section V that when a sheet of aluminium 8.1 mms. in thickness which was sufficient to absorb all the $\beta$ rays and the secondary rays excited by them was placed over the opening at the top of the ionisation chamber the saturation currents were not the same with a magnetic field applied in one direction as those obtained with the same field reversed. This lack of symmetry in the values of the saturation currents obtained when screens of aluminium were used is illustrated by curves E and E′ in Fig. 13. In the experiments with lead and tin screens no effect of this kind was observed, and in order to clear up the matter an additional series of experiments was carried out to ascertain if possible the cause of it in the case of aluminium.

1. In the first experiment a thickness of 4.73 mms. of aluminium was placed over the opening at the top of the chamber, and above this a thickness of .964 mms. of lead. This thickness of lead, it will be remembered was found in the earlier experiments sufficient to absorb all the $\beta$ and the $\beta$ secondary radiations. It follows then, that with this screen none but the $\gamma$ rays of radium could enter the

ionisation chamber when this double thickness of lead and aluminium was placed over the top. The conductivities in the chamber for gradually increasing fields in both directions were taken and these are given in Table XVI. The second column of this Table shews a slight gradual decrease in ionisation as the $\beta$ rays were deflected into the chamber, and the fourth column shews a greater decrease as the $\beta$ rays were deflected away from the chamber. Here again it will be seen that the difference in the ionisations for the directions of the magnetic field was approximately of the same magnitude when there was 8.4 mms. of aluminium over the ionisation chamber. Since none but $\gamma$ rays could enter the chamber this difference in ionisation must have been due to the action of the magnetic field in the chamber on the secondary radiation issuing from the back of the aluminium screen under the excitation of the $\beta$ rays.

2. The next experiment was to place the radium protected by the lead cylinder on the side of the ionisation chamber directly opposite to its former position. The same aluminium screen 8.14 mms. in thickness was placed over the chamber as before, and the $\beta$ rays were again deflected down into the chamber by a suitably directed magnetic field and afterwards upward and away from it with the field reversed. The results are given in Table XVII. The numbers thus recorded shew the same characteristics as when the radium was in the first position. When the magnetic fields were such as to deflect the $\beta$ rays downwards into the chamber the ionisation decreased but slightly. On the other hand a considerably greater decrease took place when the $\beta$ rays were deflected in the opposite direction.

3. A third experiment was carried out with the radium and its lead protection placed back in the original position. One sheet of tinfoil .0196 mms. in thickness was inserted over the top of the ionisation chamber and 8.14 mms. of aluminium was then placed over the tin. Readings were then taken of the conductivity in the chamber for the two deflections. These readings are given in Table XVIII, and the curves A and A′ representing them are drawn in Fig. 16. These curves and the curves E and E′ drawn in Fig. 13 are on the same scale. A comparison of the latter which correspond to a screen of 8.14 mms. of aluminium alone over the top of the chamber, with the curves A and A′ in Fig. 16, makes it clear that the insertion of the sheet of tinfoil beneath the aluminium screen brought the curves representing the two deflections more nearly into coincidence. The natural conclusion would be then, that for a greater thickness of tinfoil below the aluminium the two curves representing the ionisations for the two deflections would coincide. To test this connection four

sheets of tinfoil or a thickness of .0784 mms. were placed above the opening of the chamber and over this the 8.14 mms. of aluminium. The conductivity in the chamber was then measured for different magnetic fields. The results are given in Table XIX, and curve B illustrating them is shewn in Fig. 16. The numbers in the table and the curve both shew that with a screen made up in this way the conductivities in the chamber were identical for magnetic fields of equal intensity in either direction. This experiment shewed clearly that the effect under consideration was due to a peculiarity in the secondary radiation emitted by the aluminium.

4. In the fourth experiment the radium protected by the lead cylinder was placed vertically above the ionisation chamber and also above the poles of the magnet in such a way that the pencils of rays from the radium were directed straight into the ionising chamber. The saturation currents for magnetic fields in both directions when the 8.14 mms. of aluminium alone covered the chamber were then measured. From the values of these currents which are recorded in Table XX it will be seen that the ionisation corresponding to any selected field intensity was the same for both directions of the field. Since the disposition of the apparatus in this experiment was symmetrical it follows that the effect noted with the previous arrangement was not only connected with some special property of the secondary radiation excited in the aluminium by the gamma rays, but it also was due evidently to a non-symmetrical configuration of these secondary rays in the ionising chamber.

The following is offered as an explanation of the foregoing experiments.

In Fig. 17, A represents the ionisation chamber, B the electrode, CD the aluminium screen, and R the position of the radium in the non-symmetrical arrangement. From a consideration of the figure it is evident that the line RA, which is the axis of a pencil of $\gamma$ rays entering the chamber will mark the line of greatest intensity of these rays, since for all other rays the metal path traversed is longer and consequently the absorption is greater. It follows then that RA will also represent the direction of the axis of the pencil of secondary rays of greatest intensity issuing from the back of the aluminium plate. If then the magnetic field was applied in such a direction as to deflect the primary $\beta$ rays down into the chamber, this field since the chamber was so situated as to be affected by the field, would deflect the secondary rays issuing from the back of the aluminium screen in the same direction. With the field in the opposite sense the primary $\beta$ rays would be deflected upwards and away from the chamber, and the secondary rays in the chamber would also be turned by this field

in a similar way, i.e., with one direction of the field the axis of the pencil of secondary rays corresponding to RA would be turned anti-clockwise, while with the field reversed this pencil would undergo a clockwise deflection. From the diagram shewn in Fig. 17 it can be seen that when the pencil of maximum intensity RA is given a clockwise rotation the air path traversed by it will be lessened, and consequently the ionisation produced by it reduced. On the other hand, with the anti-clockwise rotation the length of path traversed by this pencil will be increased, and hence one should not expect the magnitude of the decrease in ionisation following the application of the field producing this deflection to be as great as when the field applied caused the rays to be deflected in the opposite sense. It is evident, too, that the tertiary rays excited on the walls of the chamber by the aluminium secondary rays would be greater in the case of the anti-clockwise rotation of the secondary rays than in experiments when the rotation of these rays was in the opposite direction. One naturally inquires why this effect did not appear in the experiments when tin and lead were used as coverings for the openings into the chamber, and also when a thickness of 0.0784 mms. of tinfoil was placed below the aluminium cover. The probable explanation is that the transmitted secondary rays from tin and lead are not so effective ionising agents or so good exciters of tertiary rays as the secondary rays from aluminium. The effect even in the case of aluminium is small although quite noticeable, and it is probable therefore, with the weaker secondary rays from the tin and lead that the effect would be very much less, and consequently masked by the other influences present.

The experiments which have just been described are also interesting for the light which they throw on the nature of the transmitted secondary radiation excited in the metals aluminium, tin, and lead by $\gamma$ rays. According to the argument which has been presented, it follows from Bragg's conclusions, since the secondary rays from aluminium are better ionisers than those from tin and lead, that the particles constituting these secondary rays must be endowed with smaller velocities than those constituting the secondary radiation from the other two metals. The transmitted $\gamma$ excited secondary rays from aluminium should therefore, from this point of view, be more easily absorbed than those emitted by tin and lead.

This conclusion regarding the character of the transmitted secondary radiation excited in aluminium by $\gamma$ rays is in accord with the conclusions of McClelland,[1] Starke[2] and others, who have found

[1] McClelland, Trans. Roy. Dublin Soc. 8, p. 169, 1905.
[2] Starke, Le Radium, Feb., 1908.

an exceptionally high co-efficient of absorption for the reflected secondary rays excited by $\beta$ and $\gamma$ rays in this metal.

*VII. A Comparison of the Secondary Radiations excited in different Metals by $\beta$ Rays.*

Some conclusions of interest can also be drawn from the results of the experiments of the present investigation regarding the secondary rays excited in different metals by $\beta$ rays. For the purpose of making a comparison, the thicknesses of the limiting absorbing layers of the three metals studied with both reflected and transmitted rays are collected in Table XXI, and in Fig. 18 curves are drawn with the thicknesses of the absorbing layers as abscissæ and the densities of the absorbing substances as ordinates. The curve A is plotted from the results of the transmitted radiation experiment, while the curve B corresponds to the measurements on the reflected rays. It will be noticed that the scale of abscissæ used for the latter curve is only one tenth that adopted in laying out the former. From the results in the table and from the form of the curve it will be seen that the thicknesses of the absorbing materials required to stop the $\beta$ and $\beta$ secondary rays were not directly proportional to the densities, but that as the densities decreased it required greater thicknesses to stop the rays than should have been expected from density consideration alone.

It is highly probable that the maximum depth from which the secondary rays come on the front side of a metal plate when primary $\beta$ rays impinge on it, represents the thickness that the secondary rays excited by the primary ones will penetrate in that metal. Now, if the secondary rays excited by the primary in the three metals are all of the same penetrability, one should expect on the assumption that they are $\beta$ rays, that numbers representing the maximum penetrability found for these secondary rays would follow the same absorption law with reference to the density that the numbers representing the maximum penetrabilities of the primary radiation followed. In other words, the two curves A and B should be similar in form if the secondary rays excited in the three metals possess the same penetrability. But it is clear from the manner in which the two curves intersect in the figure that they do not typify the same absorption law. It will be seen from the curve B that the maximum penetrabilities of the secondary $\beta$ rays, as determined by the reflection experiments, approximate very closely to a linear relation which exhibits in a striking manner the important result that secondary rays excited in plates of different metals when $\beta$ rays are allowed to fall on them are the more penetrative the greater the density of the metal of which the reflector is made.

*VIII. Summary of Results.*

1. The $\beta$ radiation from radium bromide which includes the $\beta$ radiations from all the radium products in the equilibrium state will not produce any ionisation on the far side of a plate of aluminium 7 mms. in thickness, of a plate of tin 2.5 mms. in thickness, or of a plate of lead .9 mms. in thickness.

2. The maximum secondary radiation emitted from the front side of plates of the metals aluminium, tin, and lead, when bombarded by $\beta$ rays are given by the following thicknesses:

| | |
|---|---|
| Aluminium | 0.4 mms. |
| Tin | 0.24 mms. |
| Lead | 0.16 mms. |

3. The transmitted secondary radiations excited by $\gamma$ rays in lead and tin are more penetrating than the transmitted secondary radiation excited in aluminium by the same rays.

4. When $\beta$ rays are allowed to fall in turn on reflectors of different metals, it is found that the greater the density of the metal from which the reflector is made the greater is the penetrability of the reflected secondary rays excited by the $\beta$ radiation.

5. From the experiments on the transmission of $\beta$ rays through sheets of aluminium foil, it has been shewn that when very thin sheets of the metal are used, the ionisation at first contributed by the transmitted secondary radiation excited by the $\beta$ rays is greater than that lost through absorption of the primary rays.

In conclusion I wish to express my best thanks to Prof. McLennan, at whose suggestion the investigation was undertaken, for his help and advice and unfailing kindness throughout the course of the research.

TABLE I.

Ionisation by $\beta$ transmitted secondary rays from tinfoil with primary rays deflected down into chamber.

| Current in magnet (amp.) | Saturation currents (arbitrary scale) with different thicknesses of tinfoil. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I mm. 0.00 | II mm. 0.0196 | III mm. 0.0784 | IV mm. 0.1568 | V mm. 0.3136 | VI mm. 1.254 | VII mm. 1.96 | VIII mm. 3.136 |
| 0.0 | 46.6 | 42.3 | 27.3 | 23.3 | 19.4 | 16.25 | 14.59 | 13.08 |
| 0.2 | 51.5 | 53.9 | 29.7 | .... | .... | .... | .... | .... |
| 0.45 | 128.4 | 84.2 | .... | .... | .... | .... | .... | .... |
| 0.85 | 292.0 | 196.5 | 52.0 | 27.0 | 20.3 | .... | 14.51 | 12.87 |
| 1.15 | 348.5 | 294.8 | 86.0 | .... | .... | .... | .... | .... |
| 1.65 | 360.0 | 343.2 | 152.0 | 62.6 | 25.0 | .... | .... | 12.73 |
| 2.2 | .... | 327.3 | 221.1 | 115 | .... | 16.19 | .... | .... |
| 2.5 | 305 | .... | .... | .... | 45.8 | 16.19 | .... | 12.66 |
| 3.2 | 170.2 | .... | 161.9 | .... | .... | .... | 14.44 | .... |
| 4.0 | .... | 149.3 | .... | 97.4 | 62.8 | 16.13 | .... | 12.61 |
| 5.0 | .... | .... | 96.9 | 79.0 | 57.0 | 16.48 | 14.35 | 12.45 |
| 6.6 | .... | 81.1 | 69.1 | .... | 46.7 | .... | 14.21 | .... |
| 7.0 | 62.5 | 73.4 | .... | 58.5 | .... | 16.43 | .... | 12.29 |
| 10.0 | 34.0 | 50.7 | 47.1 | 45.2 | 34.5 | 16.22 | 14.02 | 12.28 |
| 15.0 | 20.8 | 35.4 | 29.8 | 31.5 | 25.7 | 15.9 | 13.96 | 12.22 |
| 20.0 | 16.0 | 27.5 | 26.5 | 25.4 | 22.5 | 15.64 | 13.85 | .... |
| 25.0 | .... | .... | .... | .... | 20.0 | 15.51 | 13.82 | .... |
| 27.5 | .... | 23.0 | 22.2 | 22.0 | .... | .... | .... | 12.1 |

TABLE II.

Ionisation by $\beta$ transmitted secondary rays from tinfoil with primary rays deflected up from chamber.

| Current in magnet. | Saturation current (arbitrary scale) for different thicknesses of tinfoil. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. 0.0196 | III mm. 0.0784 | IV mm. 0.1568 | V mm. 0.3136 | VI mm. 1.254 | VII mm. 1.96 | VIII mm. 3.3136 |
| 0.0 | 46.6 | 41.7 | 26.4 | 22.1 | 19.1 | 16.25 | 14.55 | 12.82 |
| 0.7 | 14.7 | .... | .... | .... | .... | .... | .... | .... |
| 0.85 | .... | 23.2 | 20.9 | 20.1 | 18.3 | .... | 14.34 | .... |
| 1.45 | 10.5 | .... | .... | .... | .... | .... | .... | .... |
| 1.70 | .... | .... | 19.5 | 19.0 | 18.0 | .... | .... | 12.56 |
| 1.80 | .... | 18.4 | .... | .... | .... | 15.84 | .... | .... |
| 2.5 | .... | .... | .... | .... | 17.9 | 15.84 | .... | 12.52 |
| 3.8 | 7.6 | 17.3 | 17.9 | 18.2 | 17.7 | 15.73 | .... | 12.44 |
| 5.0 | .... | .... | 17.8 | 17.9 | 17.6 | 15.68 | .... | 12.4 |
| 6.6 | 7.41 | .... | 17.5 | 17.8 | 17.3 | 15.58 | 14.15 | 12.36 |
| 7.0 | .... | 16.9 | .... | .... | .... | .... | .... | .... |
| 10.0 | .... | 16.8 | .... | .... | 17.2 | 15.21 | 14.09 | 12.26 |
| 12.0 | .... | .... | 17.9 | 17.6 | .... | .... | .... | .... |
| 15.0 | 7.23 | 16.6 | 17.9 | .... | 17.0 | 15.29 | 13.9 | 12.10 |
| 17.5 | .... | .... | .... | .... | .... | .... | .... | .... |
| 21.0 | 7.14 | 16.3 | .... | 17.3 | 16.9 | 15.17 | 13.87 | 12.06 |
| 26.5 | .... | 16.2 | 17.6 | 17.2 | 16.8 | .... | 13.79 | .... |

TABLE III.

| Remarks | Saturation current. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Thickness of tin over the top of chamber | mm. 0.0 | mm. 0.0196 | mm. 0.039 | mm. 0.0784 | mm. 0.1568 | mm. 0.3136 | mm. 1.254 | mm. 1.96 | mm. 3.136 |
| I. Max. $\beta + \beta$ secondary $+\gamma+\gamma$ secondary + natural ionisation | 360.0 | 343.2 | 287.5 | 230. | 113.8 | 67.8 | 17.2 | 14.4 | 12.37 |
| II $\gamma +$ $\gamma$ secondary + natural ionisation | 7.37 | 16.9 | 17.8 | 17.7 | 17.7 | 17.6 | 15.4 | 14.1 | 12.37 |
| III $\beta +$ $\beta$ secondary ionisation | 352.63 | 326.3 | 269.7 | 212.3 | 96.1 | 50.2 | 1.8 | 0.3 | 0.0 |

TABLE IV.

Ionisation by $\beta$ reflected secondary rays from tinfoil.

| Current in magnet | Saturation currents (arbitrary scale). Different thicknesses of tinfoil. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. 0.0081 | III mm. 0.0196 | IV mm. 0.039 | V mm. 0.0784 | VI mm. 0.1568 | VII mm. 0.6272 | VIII mm. 1.96 |
| 0.0 | 1086 | 1121.9 | 1165 | 1198 | 1225 | 1230 | 1234 | 1230 |
| 0.85 | .... | 826.4 | 858.2 | 864.6 | 881.2 | 891.4 | 898.4 | 920 |
| 0.9 | 821.4 | .... | .... | .... | .... | .... | .... | .... |
| 2.5 | 267.4 | 230.3 | 224.1 | 294.8 | 225.7 | 226.3 | 232.1 | 250.2 |
| 4.5 | 103.5 | 104.5 | 95.8 | 98.2 | 91.2 | 95 | 95.0 | 86.4 |
| 6.75 | 68.0 | 72.3 | 64.9 | 64.9 | 57.5 | 61.8 | 62.5 | 57.3 |
| 10.0 | 58.9 | 61.4 | 53.9 | 55.4 | 47.6 | 51.5 | 50.8 | 47.7 |
| 15.0 | 54.2 | 54.7 | 49.1 | 48.7 | 43.9 | 47.3 | 46.7 | 43.5 |
| 22.0 | 51.8 | 50.4 | 46.3 | .... | 43.4 | 44.9 | 44.9 | 41.0 |
| 23.5 | .... | .... | .... | 46.0 | .... | .... | .... | .... |
| 28.5 | .... | 48.5 | 44.7 | .... | 42.6 | 43.2 | 43.0 | .... |
| 29.5 | .... | .... | .... | 44.7 | .... | .... | .... | .... |

TABLE V.

Ionisation by $\beta$ transmitted secondary rays from lead foil with primary rays deflected down into chamber.

| Thickness of tin foil over bottom of chamber. | Max. $\beta + \beta$ secondary $+ \gamma + \gamma$ secondary $+$ natural ionisation. | $\gamma + \gamma$ secondary $+$ natural ionisation. | Max. $\beta + \beta$ secondary ionisation. |
|---|---|---|---|
| mm. 0.0000 | 1086 | 51.8 | 1034.2 |
| 0.0081 | 1121 | 47.5 | 1073.5 |
| 0.0196 | 1165 | 44.7 | 1116.3 |
| 0.039 | 1198 | 44.7 | 1153.3 |
| 0.0784 | 1225 | 42.6 | 1182.4 |
| 0.1568 | 1230 | 43.2 | 1186.8 |
| 0.6272 | 1234 | 43.2 | 1190.8 |
| 1.96 | 1230 | 41.5 | 1188.5 |

TABLE VI.

Ionisation by $\beta$ transmitted secondary rays from lead foil with primary rays deflected down into chamber.

| Current in magnet. (amperes) | Saturation current (arbitrary scale), with different thicknesses of lead foil. | | | | |
|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. .241 | III mm. .482 | IV mm. .723 | V mm. .964 |
| 0.0 | 56.5 | 21.1 | 19.6 | 16.9 | 16.5 |
| .2 | 95.8 | .... | .... | .... | .... |
| .85 | 294.8 | 21.9 | .... | .... | 16.3 |
| 1.35 | 383.3 | .... | .... | .... | .... |
| 1.70 | 359.3 | .... | .... | .... | .... |
| 2.5 | 302.6 | 30.0 | 20.4 | 16.9 | 16.2 |
| 4 | .... | 48.7 | 22.6 | .... | 15.9 |
| 4.5 | 118.5 | .... | .... | 17.0 | .... |
| 5. | .... | 50.4 | 24.8 | 17.4 | .... |
| 6.5 | 68.0 | .... | .... | 17.34 | .... |
| 7. | .... | .... | 25.4 | .... | 15.8 |
| 10 | 41.5 | 35.4 | 24.0 | 17.03 | 15.7 |
| 15 | 26.4 | 27.9 | 21.6 | 16.45 | 15.4 |
| 22.5 | 18.0 | 23.3 | 19.5 | 16.45 | 15.4 |

TABLE VII.

Ionisation by $\beta$ transmitted secondary rays from lead foil with primary rays deflected up from chamber.

| Current in magnet. (amperes) | Saturation current (arbitrary scale) for different thicknesses of lead foil. | | | | |
|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. .241 | III mm. .482 | IV mm. .723 | V mm. .964 |
| 0. | 56.5 | 21.1 | 19.5 | 16.9 | 16.5 |
| .8 | 18.5 | 20.1 | .... | .... | 16.3 |
| 2.5 | 9.4 | 20.0 | 19.0 | 16.7 | 16.1 |
| 4.5 | .... | 19.7 | 18.8 | 16.59 | 16.0 |
| 6.5 | 8.6 | 19.5 | .... | .... | .... |
| 7.0 | .... | .... | 18.5 | 16.71 | 15.8 |
| 10 | .... | 19.1 | 18.5 | .... | 15.7 |
| 15 | 8.1 | 19.0 | 18.1 | 16.15 | 15.5 |
| 22.5 | 8.1 | 19.1 | 18.0 | 16.28 | 15.4 |

TABLE VIII.

| Remarks. | Saturation Current. | | | | |
|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. |
| Thickness of lead over the top of chamber..... | 0 | .241 | .482 | .723 | .964 |
| I. Max. $\beta + \beta$ secondary $+ \gamma + \gamma$ secondary $+$ natural ionisation.. | 383.2 | 50.9 | 25.8 | 17.5 | 15.6 |
| II. $\gamma + \gamma$ secondary natural ionisation. | 8.4 | 19.4 | 17.7 | 16.5 | 15.6 |
| III. Max. $\beta + \beta$ secondary ionisation. | 374.8 | 31.5 | 8.1 | 1.0 | 0. |

TABLE IX.

Ionisation by $\beta$ reflected secondary rays from lead foil.

| Current in magnet. (amperes) | Saturation current (arbitrary scale) for different thicknesses of lead foil. | | | | | |
|---|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. .066 | III mm. .093 | IV mm. 0.116 | V mm. .241 | VI mm. .964 |
| 0 | 1161.0 | 1315 | 1337 | 1349 | 1349 | 1340 |
| 8 | 799.0 | .... | 809.8 | .... | 818.5 | 801.3 |
| 2.5 | 146.0 | .... | 147.8 | .... | 139.8 | 145 |
| 4.5 | 64.9 | .... | 59.5 | .... | 65.3 | 63.8 |
| 6.5 | 58.9 | .... | 54.7 | .... | 54.2 | 55.5 |
| 10. | 57.8 | .... | 56.3 | 58.3 | 56.1 | .... |
| 15 | 58.9 | 57.8 | 58.6 | 58.0 | .... | 56.6 |
| 22 | 57.8 | 56.9 | 57.2 | 56.6 | 56.9 | 56.9 |
| 28 | 56.9 | 56.1 | 56.3 | 56 | 55.3 | 55.8 |

TABLE X.

| Thickness of lead over bottom of chamber. | Max. $\beta + \beta$ secondary $+ \gamma + \gamma$ secondary natural ionisation. | $\gamma + \gamma$ secondary + natural ionisation. | Max. $\beta + \beta$ secondary ionisation. |
|---|---|---|---|
| mm. | | | |
| 0. | 1161 | 57.8 | 1103.2 |
| .066 | 1315 | 56.9 | 1258.1 |
| .093 | 1337 | 56.7 | 1280.3 |
| .116 | 1349 | 57.3 | 1291.7 |
| .241 | 1349 | 55.6 | 1293.4 |
| .964 | 1340 | 56.2 | 1283.8 |

TABLE XI.

Ionisation by $\beta$ transmitted secondary rays from aluminium foil with primary rays deflected down into chamber.

| Current in magnet. amp. | Saturation currents (arbitrary scale) with different thicknesses of aluminium foil. | | | | | | |
|---|---|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. .0065 | III mm. .28 | IV mm. 1.184 | V mm. 3.41 | VI mm. 4.73 | VII mm. 8.14 |
| 0 | 77.6 | 65.7 | 25.7 | 14.6 | 13.99 | 13.12 | 12.32 |
| 2 | 117.3 | 100.8 | .... | .... | .... | .... | .... |
| .45 | 176.9 | 157.5 | 36.2 | .... | .... | .... | .... |
| .8 | 302.6 | 319.4 | 63.1 | 15.7 | 13.97 | 13.24 | .... |
| 1.3 | 365.0 | 396.5 | .... | .... | .... | .... | .... |
| 1.65 | 359.3 | 396.5 | 280.4 | 22.2 | 14.57 | .... | .... |
| 2.5 | 294.8 | 319.4 | 287.5 | 50.4 | 15.65 | 13.15 | .. |
| 4.5 | 111.6 | 127.7 | 111.6 | 73.2 | 17.42 | 13.22 | 12.24 |
| 6.5 | 63.1 | 74.2 | 68.0 | 53.7 | 20.31 | 13.42 | 12.22 |
| 10 | 37.4 | 43.2 | 22.7 | 35.5 | .... | 13.42 | 12.15 |
| 15 | 25.1 | 18.4 | 27.9 | 23.8 | 16.64 | 13.17 | 12.13 |
| 22 | 18.6 | 20.9 | 20.1 | 18.1 | 15.37 | 13.08 | 12.09 |

TABLE XII.

Ionisation by $\beta$ transmitted secondary rays from aluminium foil with primary rays deflected up from chamber.

| Current in magnet. amp. | Saturation current (arbitrary scale) for different thicknesses of aluminium foil. | | | | | | |
|---|---|---|---|---|---|---|---|
| | I mm. 0.0 | II mm. .0065 | III mm. .28 | IV mm. 1.184 | V mm. 3.41 | VI mm. 4.73 | VII mm. 8.14 |
| 0.0 | 63.1 | 71.5 | 25.9 | 14.7 | 13.93 | 13.12 | 12.37 |
| .85 | 19.8 | 11.2 | 16.3 | 13.9 | 13.74 | 13.02 | 12.27 |
| 2.5 | 11.7 | 10.3 | 11.8 | 13.1 | 13.65 | 12.90 | 12.08 |
| 4.5 | .... | 10.4 | 11.3 | 12.7 | 13.41 | 12.57 | .... |
| 6.5 | 13.5 | 10.2 | 11.0 | 12.4 | 12.90 | 12.30 | 11.51 |
| 15 | 12.6 | 10.1 | 10.7 | 12.0 | 12.72 | 11.87 | 11.11 |
| 22 | 12.3 | 10.1 | 10.6 | 11.9 | 12.46 | 11.68 | 10.89 |

TABLE XIII.

| Remarks. | Saturation current. | | | | | | |
|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| Thickness of aluminium over the top of chamber..... | 0.0 | .0065 | .28 | 1.184 | 3.41 | 4.73 | 8.14 |
| I<br>Max. $\beta+\beta$ secondary + $\gamma+\gamma$ secondary + natural ionisation..... | 365 | 396.5 | 287.5 | 79.3 | 20.3 | 13.5 | 12.2 |
| II<br>$\gamma+\gamma$ secondary + natural ionisation..... | 12.6 | 10.2 | 11. | 12.3 | 13.1 | 12.3 | 11.7 |
| III<br>Max. $\beta+\beta$ secondary ionisation..... | 352.4 | 386.3 | 276.5 | 67.0 | 7.2 | 1.2 | .5 |
| IV..... | 352.4 | 386.3 | 276.5 | 67.0 | 6.7 | .7 | .0 |

TABLE XIV.

Ionisation by $\beta$ reflected secondary rays from aluminium.

| Current in magnet. | Saturation currents. (Arbitrary Scale,) Different thicknesses of aluminium foil. | | | | |
|---|---|---|---|---|---|
| amperes. | I<br>mm.<br>.0065 | II<br>mm.<br>.026 | III<br>mm.<br>.065 | IV<br>mm.<br>.280 | V<br>mm.<br>.963 |
| 0.0 | 1106 | 1126 | 1140 | 1176 | 1181 |
| .8 | 709.8 | 716.5 | .... | .... | .... |
| .85 | .... | .... | 684.3 | 710.0 | 723.9 |
| 2.5 | 127.1 | 128.9 | 116.5 | 125.8 | 170.4 |
| 4.5 | 66.8 | 58.6 | 65.7 | 59.2 | 62.1 |
| 6.5 | 57.4 | 52.0 | 55.5 | 49.5 | 52.9 |
| 15 | 57.7 | 55.2 | 58.0 | 54.3 | 53.2 |
| 23 | 56.1 | 54.5 | 56.6 | 53.4 | 52.5 |
| 30 | .... | 53.4 | 54.7 | 52. | 51.5 |

TABLE XV.

| Thickness of aluminium foil over bottom of chamber. | Max $\beta + \beta$ secondary $+ \gamma + \gamma$ secondary $+$ natural ionisation. | $\gamma + \gamma$ secondary $+$ natural ionisation. | Max. $\beta + \beta$ secondary ionisation. |
|---|---|---|---|
| mm. | | | |
| .0065 | 1106 | 57.1 | 1048.9 |
| .026 | 1126 | 53.8 | 1072.2 |
| .065 | 1140 | 56.2 | 1083.8 |
| .280 | 1176 | 52.3 | 1123.7 |
| .963 | 1181 | 52.5 | 1128.5 |

TABLE XVI.

Thickness of lead over the top of the chamber — .964 mms.
Thickness of aluminium over the top of the chamber —4.73 mms.
Lead above aluminium.

| $\beta$ rays deflected towards chamber. | | $\beta$ rays deflected away from chamber. | |
|---|---|---|---|
| Current through magnet. | Saturation current. | Current through magnet. | Saturation current. |
| 0 amperes | 10.85 | 0 amperes | 10.68 |
| 2.5 | 10.94 | 2.5 | 10.74 |
| 4.5 | 10.87 | 4.5 | 10.37 |
| 6.5 | 10.89 | 6.5 | 10.10 |
| 10 | 10.70 | 10 | 9.88 |
| 15 | 10.67 | 15 | 9.74 |
| 22 | 10.65 | 21 | 9.60 |

TABLE XVII

Thickness of aluminium over the top of chamber—8.14 mms.
Radium on opposite of chamber from its usual position.

| $\beta$ rays deflected towards chamber. | | $\beta$ rays deflected away from chamber | |
|---|---|---|---|
| Current through magnet. | Saturation current | Current through magnet. | Saturation current. |
| 0 amperes | 12.50 | 0 amperes | 12.56 |
| 4.5 | 12.46 | .85 | 12.43 |
| 10 | 12.43 | 2.5 | 12.32 |
| 15 | 12.41 | 4.5 | 12.06 |
| 22.5 | 12.40 | 7 | 11.76 |
| .... | ..... | 10 | 11.43 |
| .... | ..... | 15 | 11.11 |
| .... | ..... | 22.5 | 10.91 |

TABLE XVIII.

Thickness of aluminium over the top of chamber—8.14 mms.
Thickness of tin over the top of chamber—.0196 mms.
Aluminium above tin.

| $\beta$ rays deflected towards chamber. | | $\beta$ rays deflected away from chamber. | |
|---|---|---|---|
| Current through magnet. | Saturation current. | Current through magnet. | Saturation current. |
| 0 amperes | 16.31 | 0 amperes | 16.26 |
| 2.5 | 16.29 | 2.5 | 16.06 |
| 4.5 | 16.08 | 4.5 | 15.77 |
| 6.5 | 15.86 | 6.5 | 15.43 |
| 10 | 15.75 | 10 | 15.38 |
| 15 | 15.60 | 15 | 14.89 |
| 23 | 15.43 | 22 | 14.74 |

TABLE XIX.

Thickness of aluminium over the top of chamber —8.14 mms.
Thickness of tin over the top of chamber—.0784 mms.
Aluminium above tin.

| $\beta$ rays deflected towards chamber. | | $\beta$ rays deflected away from chamber.. | |
|---|---|---|---|
| Current through magnet. | Saturation current. | Current through magnet. | Saturation current. |
| 0 amperes | 16.00 | 0 amperes | 16.10 |
| 2.5 | 16.04 | 4.5 | 15.69 |
| 4.35 | 15.66 | 10 | 15.56 |
| 6.5 | 15.66 | 15 | 15.39 |
| 10 | 15.44 | 22 | 15.17 |
| 15 | 15.35 | .... | ..... |
| 18 | 15.19 | .... | ..... |

TABLE XX.

Thickness of aluminium over the top of chamber—8.14 mms.
Radium vertically above chamber.

| $\beta$ rays deflected towards chamber. | | $\beta$ rays deflected away from chamber. | |
|---|---|---|---|
| Current through magnet. | Saturation current. | Current through magnet. | Saturation current. |
| 0 amperes | 15.69 | 0 amperes | 15.37 |
| 2.5 | 15.31 | 3 amperes | 15.31 |
| 4.3 | 15.13 | 4.5 | 15.23 |
| 6.4 | 14.97 | 6.3 | 14.78 |
| 10 | 14.81 | 10 | 14.66 |
| 15 | 14.89 | 15 | 14.82 |
| 22.5 | 14.72 | 22.5 | 14.74 |

TABLE XXI.

| | Lead. | Tin. | Aluminium. |
|---|---|---|---|
| Thickness required to absorb $\beta$ and $\beta$ secondary radiation..... | .9 mm. | 2.5 mm. | 7 mm. |
| Thickness giving maximum reflected secondary radiation due to $\beta$ rays..... | .16 mm. | .24 mm. | .4 mm. |
| Density..... | 11.3 | 7.3 | 2.6 |

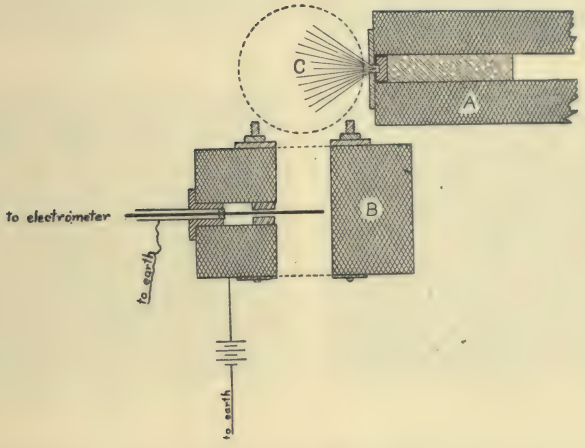



Fig. 1

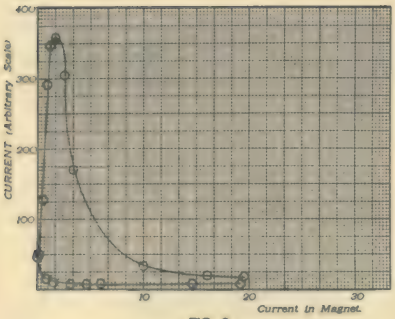



FIG. 2

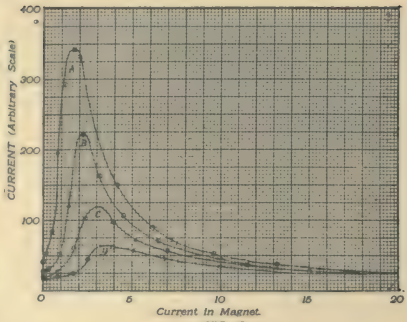



FIG. 3

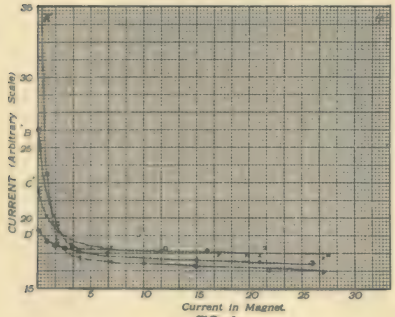



FIG. 4

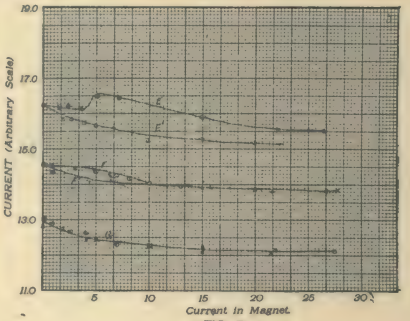



FIG. 5

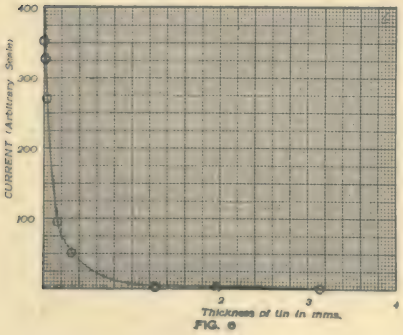



FIG. 6

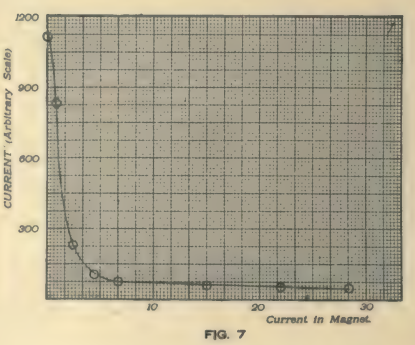



FIG. 7

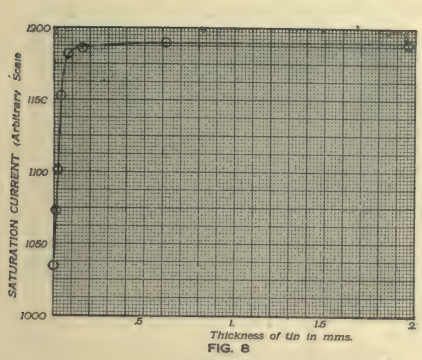



FIG. 8

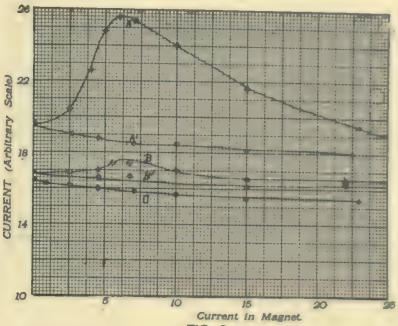



FIG. 9

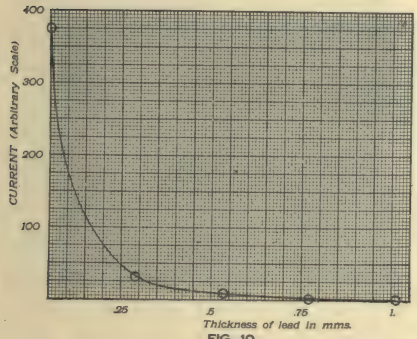



FIG. 10

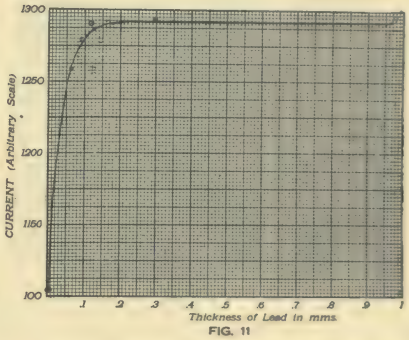



FIG. 11

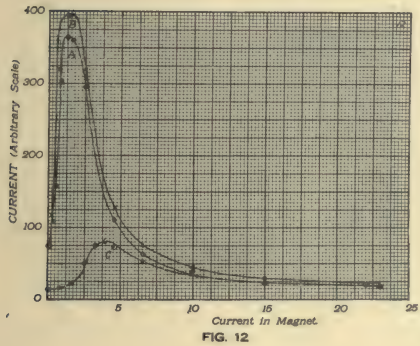



FIG. 12

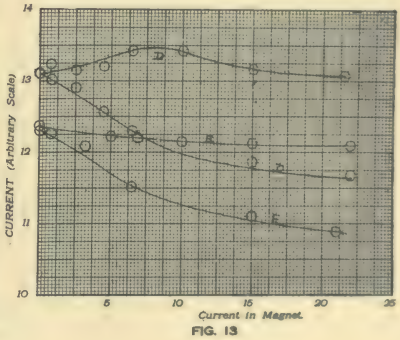



FIG. 13

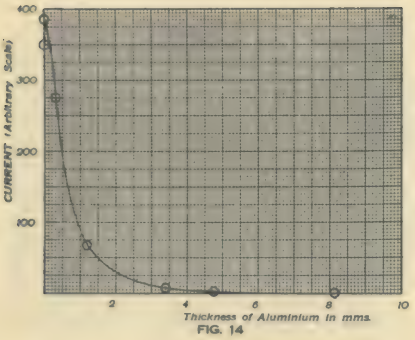


FIG. 14

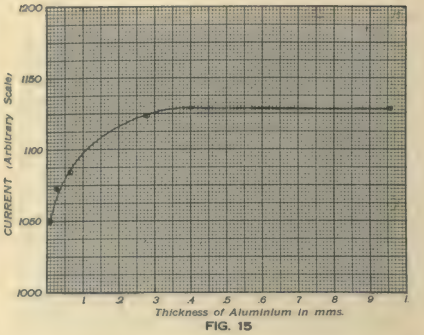


FIG. 15

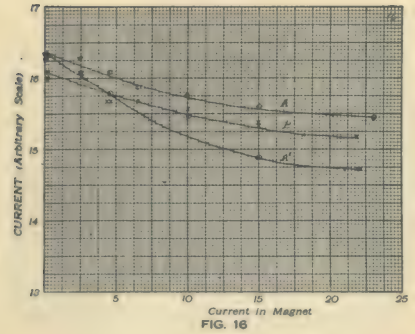


FIG. 16

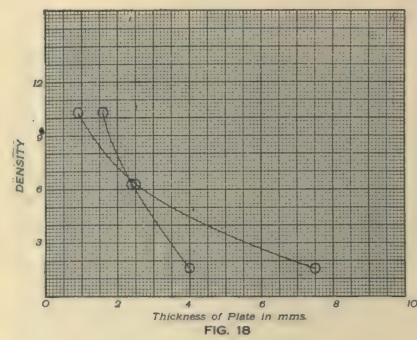


FIG. 18

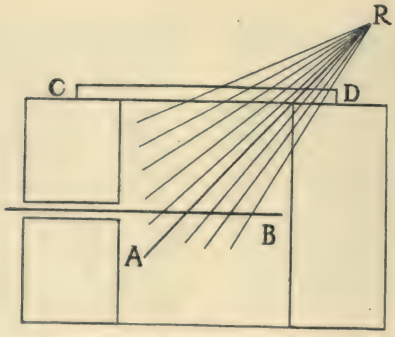


Fig. 17.

# ON THE SECONDARY RAYS EXCITED BY THE ALPHA RAYS FROM POLONIUM.—I.

BY V. E. POUND, M.A.*

(*Read 13th January, 1912*).

## I. Introduction.

RECENT researches have shewn that radioactive materials from which $\alpha$ rays are sent off also emit a radiation of negatively charged particles, which will not ionise a gas, and which has been called $\delta$ rays. The other characteristics of this radiation are that it is easily absorbed, it is easily deflected by a magnetic field and it is stopped by a small positive charge placed upon the radioactive substance emitting it. Still later researches by Logeman*[1] have shewn that when $\alpha$ rays fall on a polished piece of metal such as copper, this metal emits a secondary radiation with characteristics similar to those of the $\delta$ rays. Further, it has been found by Duane*[2] that the $\alpha$ rays lose their power to produce secondary rays at the same time that they lose their charge and their power to ionise a gas.

The present paper describes some experiments on these secondary rays produced by the $\alpha$ rays of polonium. The apparatus employed at first was somewhat similar to that used by Logeman when he proved the existence of this secondary radiation from metals bombarded by $\alpha$ rays. In the experiments to be described exhaustions were made with a Gaede pump and the pressures were measured with a McLeod gauge.

## II.—DESCRIPTION OF APPARATUS.

The apparatus used in the initial experiments is shewn in Fig. 1. It consisted of a brass cylinder about 4 cm. in diameter and 9 cm. in length which had an ebonite plug fitting into each end. Through one of these plugs was lead a brass rod which carried a round brass electrode B, about 15 mm. in diameter. The electrode B was surrounded by a circular guard ring C. Through the other plug was led another brass rod and it carried the second electrode, A. A circular surface, *ab*, of this electrode A, about 15mm. in diameter was coated with a deposit of polonium.

*Presented by Prof. J. C. McLennan.

*[1] Logeman, Proc. Roy. Soc. Series A, Vol. 78, Sept. 6, 1907. E. Aschkinass, Ann. der Phys. No. 12, 1908.

*[2] Duane, Comptes Rendus, May 25, 1908.

The distance between the polonium deposit and the surface of the electrode B was 6 mm. The polonium and the surface of the electrode B were coaxial. The brass cylinder which was made air-tight with wax was connected to the McLeod gauge and the Gaede air-pump by a tube D. The polonium coated electrode, A, was connected to a battery, and the brass electrode, B, to a sensitive quadrant electrometer. The brass cylinder surrounding the two electrodes was connected to earth.

## III.—REPETITION OF LOGEMAN'S EXPERIMENT.

The experiment which Logeman made*[1] was first repeated, and the results obtained were similar to those obtained by him with identical electrical fields. The experiment was conducted in the following manner. By means of the Gaede pump the air was pumped out from the apparatus to as low a vacuum as possible. The pressure of the air was measured by means of the McLeod gauge, and when the pressure became so low that the McLeod gauge could not measure it, which was less than 1/1000 of a millimetre of mercury the polonium was connected to earth and the rate of charging of the brass electrode opposite was measured by means of the electrometer. Then the polonium was charged to a series of different potentials by means of a storage battery, and the corresponding rates of charging of the brass electrode were ascertained. Throughout the experiment the Gaede pump was kept going continuously in order to withdraw any gas which might come from the walls of the apparatus.

The results which were obtained are given in Table I.

TABLE I.

| Pressure less than .001 mm. | Distance between electrodes 6 mm. |
|---|---|
| Voltage on polonium. | Rate of charging. |
| 0. volts | −49 |
| .44 " | −16 |
| 2.1 " | 45.1 |
| 7 " | 81 |
| 19 " | 89.5 |
| 40 " | 88.5 |
| 76 " | 86 |
| 179 " | 82 |
| 258 " | 80 |
| 502 " | 75.5 |

In column I is given the voltage applied to the polonium, and in column II the charge gained per minute by the brass electrode opposite

*[1] Proc. Roy. Soc. Vol. 78, Sept. 6, 1907.

the polonium, as measured by the quadrant electrometer. A curve representing these results is shewn in Fig. 2.

It is evident from the results given in the Table, and from the curve, that when the polonium was at zero voltage the charge gained by the brass electrode was negative. It is also evident that as the voltage on the polonium was increased positively the charge gained by the electrode increased from a negative charge to a positive one, and that at a potential of about 20 volts the rate of charging became a maximum. This result agrees with the result published by Logeman. This can be seen from the numbers recorded in his paper, a few of which are given in the following table. The results can be readily compared because the distance between the polonium and the opposite electrode was about the same as that in Logeman's apparatus.

LOGEMAN'S RESULTS.

| Distance between electrodes 5 mms. | |
|---|---|
| Potential on Polonium. | Reading of current to electrode. |
| 0 volts | −58.0 |
| 2 " | 86 |
| 12 " | 182 |
| 14 " | 185 |

It will be seen however, from the curve, that as the potential on the polonium was increased beyond 20 volts, the rate of charging of the electrode gradually decreased. This effect does not appear to have been observed by Logeman. In searching for the explanation of it, further interesting properties of the secondary rays were found by the writer which have not as yet been noted by other experimenters.

Before seeking for an explanation of the results given in Table I, and shewn graphically in Fig. 2, it is necessary to enumerate the different currents which would give a charge to the brass electrode B. In the first place there would be a current due to the passage of the $\alpha$ rays from the polonium across the space separating the polonium from the electrode. Since the $\alpha$ rays are positively charged particles this current would charge the electrode positively. Then there would be a current of negatively charged particles from the polonium which would reach the electrode. This current is known as the $\delta$ radiation and always accompanies a discharge of $\alpha$ particles. The passage of this current would give a negative charge to the electrode. Again there would be a stream of negatively charged particles omitted by the electrode. The researches of Aschkinass and Logeman have proven this stream to exist whenever a substance is bombarded by $\alpha$ rays, and it has been called the secondary radiation. The emission of this stream of negative-

ly charged particles would have the effect of charging the electrode positively. Finally, there would be a current through the air in the chamber, due to the ionisation of the air by the $\alpha$ rays. This last current would charge the electrode positively, since the polonium was positively charged. This current which we will call the ionisation current, would be, in all probability, very small, on account of the small quantity of gas in the chamber.

Let us now consider what would be the effect on these different currents of increasing the positive potential on the polonium from zero upwards. The number of $\alpha$ particles emitted per second by the polonium could not be changed by increasing the potential for it is found impossible to change the rate of emission of the $\alpha$, $\beta$ and $\gamma$ rays from the radioactive substances by any known agency. The increase of the potential on the polonium might, however, increase the speed with which the $\alpha$ particles passed from the polonium to the electrode. If this were the case, since it has been shewn by different experimenters, including Geiger and Marsden*[1] that $\alpha$ rays are reflected to some extent from the substances they strike this increase in velocity might cause a more profuse reflection of the $\alpha$ rays from the electrode. Hence as the potential was increased there would be fewer and fewer $\alpha$ particles which would remain attached to the electrode and this would cause the positive rate of charging of the electrode to decrease.

The effect of increasing the positive potential on the polonium could only tend to retard more and more of the $\delta$ rays which are negatively charged and of slow velocity. Hence, on account of the stopping of these rays, the rate of charging of the electrode positively must have increased. In fact the sharp rise in the first part of the curve shewn in Fig. 2 has been attributed by Logeman and others, and very probably correctly so, to the stoppage of the $\delta$ rays by the positive charge on the polonium.

Again the increase of the positive charge on the polonium must tend to produce a freer discharge of negative electricity from the electrode, since a positive charge on the polonium attracts negative from the electrode. The primary cause of this discharge would be, of course, the bombardment of the electrode by the $\alpha$ rays, and this is what we have called the secondary radiation. An increase in the amount of secondary radiation discharged from the electrode would increase the rate at which the electrode charged positively.

Finally, the increase of potential on the polonium would have the effect of increasing the ionisation current from the polonium to the electrode through the gas, and this would cause the positive rate of charg-

* [1] Geiger and Marsden, Proc. Roy. Soc. Ser. A. 82, July 31, 1909.

ing of the electrode to increase since the charges on the polonium were positive. There is, however, one factor which may have influenced the experiment and which must be considered here, and that is that the Gaede pump was kept going continuously in order to keep the pressure low. The readings were not taken until the pressure was less than 1-1000 of a mm. of mercury but yet the pressure may have decreased still further while the readings were being taken and on account of the decrease in the pressure the ionisation current may have also decreased. It is evident that this would cause a decrease in the positive rate of charging of the electrode.

It is seen, therefore, that, according to the above explanations of the charging of the electrode by the different currents, there are only two things which might cause a decrease in the rate of charging of the electrode positively as the potential on the polonium was raised positively. Either there might be a more profuse reflection of $\alpha$ rays from the electrode, and so reduce its rate of charging or there might be a gradual decrease in the ionisation current due to the lowering of the pressure of the air in the apparatus.

Now it is evident from the curve given in Fig. 2 that there was a gradual decrease in the rate of charging of the electrode after the potential of the polonium was increased beyond 20 volts. In order to find out how much of this decrease or whether any at all was due to the withdrawal of more air from the apparatus after it was exhausted to a very low pressure the experiments described in the following section were performed.

## IV.—IONISATION EXPERIMENTS.

In the first experiment, the polonium was charged to a positive potential of 77 volts. It was found, that with the polonium at this potential the $\delta$ radiation was practically all stopped. The Gaede pump was started and the air which had stood in the apparatus for a week, at atmospheric pressure, was pumped out until the pressure as measured by the McLeod gauge was less than 1/1000 of a mm. of mercury. The time taken by the pump to do this was about 15 minutes. Then, while the pump was kept continuously going, readings were taken of the rate of charging of the electrode at different intervals of time. It was hoped in this way to get some idea of the effect of the withdrawal of the air on the ionisation current between the polonium and the electrode. In Table II the results obtained are given.

TABLE II.

Air in apparatus.

| Brass electrode B. | Voltage on polonium = 77 volts. |
|---|---|
| Time. | Current to electrode. |
| 0 minutes | 97 |
| 5 " | 81 |
| 10 " | 76 |
| 15 " | 67.5 |
| 25 " | 64 |
| 120 " | 59 |
| 130 " | 59 |

The first column states the time between any reading and the initial reading, while the second column gives the rate at which the electrode charged up.

As shown by the table the rate at which the electrode gained a charge decreased with the time and finally came to a constant value.

In this experiment the polonium was at the same voltage all the time, hence there could be no change in the rate of charging of the electrode due to a change in voltage. Therefore, according to the theory of the charging of the electrode as outlined in the previous section, the gradual drop in the rate of charging of the electrode as the time passed could only be due to a decrease in the ionisation current through the gas. This decrease could be attributed to a farther withdrawal of air from the apparatus by the pump after the pressure had been reduced to less than 1/1000 of a mm. of mercury. If this were the case this decrease in ionisation would continue until the pressure of the air in the vessel reached a constant value. Then the air withdrawn by the pump would be equal to the air which oozed out from the sides of the vessel. The final constant value for the rate of charging of the electrode would denote this equilibrium condition between the air taken away by the pump and the air which oozed out from the walls of the chamber.

If the above explanation is correct then if the apparatus were filled with another gas than air such as hydrogen, and the experiment were repeated as with the air there would again be a final pressure and also a final ionisation current through the hydrogen. But on account of the different nature of the two gases this final ionisation current would be different in the two cases and hence the final rate of charging of the electrode would also be different in the two cases.

In order to find out whether this was true the apparatus was filled

with pure and dry hydrogen and left standing over night at atmospheric pressure. Previously the apparatus had been depleted as much as possible of air by keeping it at low pressure and pumping out the air which came from the walls. The polonium was charged to a positive potential of 77 volts, the hydrogen was pumped out to less than 1/1000 of a mm. of mercury, and then readings were taken as with the air of the rate of charging of the brass electrode and are given in the following table.

TABLE III.

Hydrogen in Apparatus.

Brass electrode Voltage on polonium = 77 volts;

| Time. | Current to electrode. |
|---|---|
| 0 minutes | 86.6 |
| 6 " | 73.1 |
| 16 " | 65.1 |
| 31 " | 62.6 |
| 91 " | 59.5 |
| 95 " | 59.5 |
| 121 " | 59.0 |

It will be seen on looking at the Table that there was a decrease in the rate of charging of the electrode with the time as with the air. On comparing Table II and Table III it will also be seen that the initial rates of charging of the electrode were different with the two gases but the final rates were the same. The experimental results therefore, did not agree with the predicted results, for it was predicted that the final rates of charging of the electrode would be different using two different gases on account of the difference in the final ionisation currents through air and through hydrogen. The experimental results, go to show that the final ionisation currents were the same. This seemed hardly possible on account of the difference in density of the two gases. Another explanation of the reason why these two final rates of charging were the same was therefore looked for. The simplest one that suggested itself was that when the final rates of charging were the same, there was such a small quantity of either air or hydrogen in the apparatus that no ionisation current was possible.

The next question that naturally arose was whether all of the drop in the rate of charging of the electrode was due to a drop in the ionisation current through the air and through the hydrogen. In order to answer this question the following experiment was performed. It was found that if arc light carbon was used as the electrode instead of brass, there was a greater drop in its rate of charging than when brass was used

under the same conditions. Accordingly the brass electrode was removed from the apparatus and a similar shaped piece of carbon was put in. The polonium was charged to a positive potential of 78 volts, and the pump was started exhausting the air which was initially at atmospheric pressure. Seven minutes after the pump was started readings were taken of the pressure of air in the vessel as measured by the McLeod gauge, and the rate of charging of the carbon electrode. Similar readings were made at different intervals of time after the initial readings. The pump was kept going continuously throughout all the readings. The results are given in the following table.

TABLE IV (*a*)

Air in Apparatus.

Carbon Electrode. Charge on Pol.=78 volts.

| Pressure of air in vessel. | Time from initial reading. | Current to electrode. |
|---|---|---|
| .008 mm. | 0 minutes | 46 |
| .004 " | 1 " | 42 |
| .002 " | 5 " | 38 |
| < .001 " | 15 " | 34·5 |
| < .001 " | 30 " | 31·5 |
| < .001 " | 60 " | 29.0 |
| < .001 " | 120 " | 29. |

The pump was then stopped and while the pressure gradually increased as the air flowed out from the walls of the apparatus, the series of readings were continued and are given below.

TABLE IV (*b*).

| Pressure of air in vessel. | Time from initial reading. | Current to electrode. |
|---|---|---|
| < .001 mm. | 127 minutes. | 29 |
| .002 " | 126 " | 29 |
| .005 " | 129 " | 30.5 |
| .009 " | 134 " | 30.5 |
| .012 " | 139 " | 31 |
| .018 " | 146 " | 32.5 |
| .022 " | 153 " | 33 |
| .027 " | 161 " | 34 |
| .035 " | 171 " | 35·5 |

If the results that were obtained while the pressure of the air was decreasing are compared with the results obtained while the pressure was increasing as given in Table IV. and shewn graphically in Fig. 3, it will be seen that at any given pressure, the rate of charging of the electrode was greater as the pressure was decreasing than as it was increasing. It will also be seen that the rate of charging at a pressure of .035 mm. of mercury as the pressure was increasing was very much less than the rate of charging at much smaller pressures as the pressure was decreasing. These results shew clearly then, that the decrease in the rate of charging of the electrode as the air was pumped out of the apparatus was not all due to a decrease in the ionisation current through the gas. For, since the ionisation current is only dependent on the pressure of the air in the chamber, it should have the same value at like pressures whether the pressure was decreasing or increasing.

If the decrease in the rate of charging of the electrode with the time was not all due to a decrease in the ionisation current through the gas there must be some other reason for this decrease. As shewn in Section III there are three other currents which cause the electrode to charge up besides the ionisation current. These are, the $\alpha$ ray current from the polonium, the $\delta$ rays current from the polonium and the secondary ray current from the electrode. It has been shewn by an experiment in Section III that a positive potential of 20 volts is sufficient to stop practically all the $\delta$ ray current. Therefore, in this experiment, the only currents which charged up the electrode besides the ionisation current were the $\alpha$ ray current and the secondary radiation current. Either both, or one of these currents, then, must have had a decrease in intensity as well as the ionisation current in order to produce the total decrease in the rate of charging of the electrode as found by experiment. The decrease in intensity of the $\alpha$ rays from polonium with the time, has been studied by various experimenters and they have found the intensity falls to half value in 140 days. The time taken by the experiment was about three hours so that in this short interval of time the decrease in intensity of the $\alpha$ rays was practically nothing. Hence there must have been a considerable decrease in the intensity of the secondary radiation emitted by the carbon from the time when the first reading of the rate of charging of the electrode was taken.

The causes, then, of the decrease in the rate of charging of the electrode with the time as found in the above experiment was a small decrease in the ionisation current through the air as the pressure was reduced and a large decrease in the secondary rays sent off by the carbon. The same causes will account for the decrease in the rate of charging of the brass electrode used in the first two experiments of this section, and must also be considered when the results of the experiment described in Section III are explained. Before continuing experiments with

the object of a further elucidation of the results described in Section III it was thought well first to make an extended study of the phenomenon of the decrease in the intensity of the secondary radiation as made evident by the foregoing experiments.

## V. EXPERIMENTS ON THE "FATIGUE" OF SECONDARY RAYS.

The experiments described in Section IV shew that there was a decrease in the secondary radiation sent off by carbon bombarded by $\alpha$ rays as the air was pumped out of the apparatus in which the carbon was placed. This decrease may be called a fatigue of the secondary rays for the effect is similar to that observed in the case of the photo-electric fatigue. The phenomenon of the photo-electric fatigue has been studied extensively, and various reasons have been suggested for it. One of the reasons which have been advanced is that the substance which emits the photo-electric radiation becomes impoverished of available negative corpuscles. If the fatigue in the present experiments were due to a decrease in the number of available negative corpuscles, this decrease must have been all at the surface since the exciting $\alpha$ rays have only a small penetrability. If the decrease were due to this cause, it is probable that if air were admitted into the apparatus again, the electrode would regain its normal condition. To test this the following set of experiments was performed.

A fresh piece of carbon was placed in the apparatus, a positive charge of 80 volts was put on the polonium, the Gaede pump was started, and at a definite interval of time after the starting of the pump, readings were taken of the rates of charging the carbon electrode, and of the corresponding pressures of air in the apparatus. These readings were continued until there was practically no further decrease in the rate of charging of the electrode.

The readings are given in the following table:

TABLE V.

Fresh carbon electrode. Air in apparatus. Charge on Pol. = 80 volts.

| Pressure of air in vessel | Time from initial reading taken seven minutes after starting pump. | Current to electrode. |
|---|---|---|
| .007 mm. | 0 minutes. | 124.7 |
| .002 " | 5 " | 78.2 |
| .001 " | 15 " | 50.7 |
| < .001 " | 25 " | 41.2 |
| < .001 " | 41 " | 35.2 |
| < .001 " | 65 " | 31.2 |
| < .001 " | 87 " | 28.2 |
| < .001 " | 123 " | 26.2 |

The carbon was left in the evacuated apparatus, bombarded by $\alpha$ rays from the polonium for one week in order that it should get thoroughly fatigued to the production of secondary rays. Then the apparatus was filled with air at atmospheric pressure and again left standing for one week. At the end of this time the experiment described above was repeated and the readings are given below.

TABLE VI.

Fatigued carbon electrode. Air in Apparatus Charge on Pol. = 80 volts.

| Pressure of air in vessel | Time from initial reading taken seven minutes after starting pump | Current to electrode |
|---|---|---|
| .008 mm. | 0 minutes | 32.7 |
| .003 " | 5 " | 30.2 |
| .002 " | 15 " | 29.2 |
| .001 " | 36 " | 24.7 |
| < .001 " | 60 " | 22.3 |

After this experiment was completed the apparatus was immediately filled with air at atmospheric pressure and left standing for 22 hours. Then the above experiment was again repeated with the following results.

TABLE VII.

Fatigued carbon electrode Air in Apparatus Charge on pol. = 80 volts.

| Pressure of air in vessel | Time from initial reading taken seven minutes after starting pump | Current to electrode. |
|---|---|---|
| .004 mm. | 0 minutes | 25.3 |
| .001 " | 5 " | 22.8 |
| < .001 " | 22 " | 21.8 |

The results given in the last two columns of Tables V-VII are represented by curves shewn in Fig 4. The upper curve is plotted from the results given in Table V. the middle curve from Table VI and the lower curve from Table VII.

It will be seen on looking at the curves that each has a gradual drop. This drop represents both the decrease as time went on in the rate at which the carbon electrode sent out secondary rays and the decrease in the ionisation current across the air gap between the polonium and the electrode beginning at a certain definite interval of time after the first

air was taken from the apparatus. It will be seen also on comparing the curves that the initial point of the upper curve is much higher than the initial points of the lower curves. Also the upper curve decreases much more quickly than the lower curves, until finally the three curves all come together. Now the decrease in the ionisation current through the air space with the time would be the same in all three experiments because this decrease is dependent on the air pressure and, as the pump was kept going regularly the air pressure in all three cases would be the same at equal intervals of time after the pump was started. Hence since the upper curve shews a much greater drop than the two lower curves, there must have been a much greater decrease in the secondary radiation in the first experiment than in the two latter experiments. Therefore there must have been a much more copious emission of secondary rays at the beginning of the first experiment than at the beginning of the other two experiments. This is indicated by the height of the initial point of the upper curve above the initial points of the other two curves.

The above experiments therefore shew that when fresh carbon is used as an electrode and subjected to bombardment by $\alpha$ rays and the air withdrawn from around the carbon, there is a great decrease in the secondary rays as time goes on until finally the secondary rays emitted reach a constant value. Then, if the carbon is kept *in vacuo* for some time (one week) it will not regain its primary power of emitting secondary rays by being again surrounded by air while still under bombardment by $\alpha$ rays even for periods of time extending up to 22 hours.

The next experiments that were performed were for the purpose of finding out whether this same carbon would send out secondary rays with their initial intensity if it were placed in an atmosphere of hydrogen instead of air. The apparatus was first filled with dry hydrogen, produced from zinc and acidulated water and left at atmospheric pressure for four hours. Then as before a positive charge of 80 volts was put on the polonium, the pump was started, and at a definite interval of time after starting the pump, a series of readings was taken of the rate at which the carbon electrode charged up, and the pressure of the hydrogen in the apparatus. The readings are given in the following table.

TABLE VIII.

| Fatigued carbon electrode. | Hydrogen in Apparatus. Charge on pol. = 80 volts. | |
|---|---|---|
| Pressure of hydrogen in vessel | Time from initial reading taken four minutes after starting pump | Current to electrode. |
| .006 mm. | 0 minutes | 24.5 |
| .003 " | 6 " | 23.0 |
| < .001 " | 15 " | 22 |
| < .001 " | 31 " | 22 |
| < .001 " | 56 " | 22 |

Next the apparatus was filled with hydrogen at atmospheric pressure and left standing for eighteen hours. A series of readings were taken as before and are given below.

TABLE IX.

| Fatigued carbon electrode | Hydrogen in apparatus Charge on polonium = 80 volts. | |
|---|---|---|
| Pressure of hydrogen in vessel | Time from initial reading taken four minutes after starting pump | Current to electrode |
| .005 mm. | 0 minutes | 25.7 |
| .002 " | 5 " | 24.7 |
| < .001 " | 15 " | 24 |
| < .001 " | 30 " | 23.5 |
| < .001 " | 62 " | 23.5 |

It will be noticed that in these two last experiments with the hydrogen the first reading was taken four minutes after the pump was started while in the three experiments with the air the first reading was taken seven minutes after the pump was started. The reason for this was that the pump reduced the pressure of the hydrogen much quicker than the air and it was desired to take the first readings for both hydrogen and air at approximately the same pressure.

From the results given in the last two column of Tables VIII and IX the two lower curves of Fig. 5 are plotted, while the upper curve of Fig. 5 is plotted from the results given in the last two columns of Table V. The latter curve pictures the way in which the rate of charging of the fresh carbon electrode decreased with the time, while the former curves shew how the rate of charging of the fatigued carbon electrode, which had been left in hydrogen at atmospheric pressure, decreased with the time.

It will be noticed that there is hardly any drop in the lower curves

and a great drop in the upper curve. It will also be seen that the rate of charging of the fatigued electrode as indicated by the lower curves is nearly the same as the final value of the rate of charging of the fresh electrode as indicated by the upper curve Hence the above experiments indicate that the carbon electrode did not regain any of its primary power of producing secondary rays by being surrounded by hydrogen at atmospheric pressure.

The above experiments therefore shew that a carbon electrode which has been fatigued to the production of secondary rays and left *in vacuo* for a long time will not regain its primary power of producing secondary rays, by simply being placed in an atmosphere of either air or hydrogen. Hence the fatigue of the carbon is not due to a temporary loss of negative corpuscles which can readily be regained from air or hydrogen when these gases are allowed to surround the carbon.

The next experiments that were tried were to find out whether a piece of carbon would regain its power of producing secondary rays if it were fatigued for a very short time only. A fresh piece of carbon was placed in the apparatus and a set of experiments similar to the ones described above was performed, except that instead of leaving the carbon in the evacuated chamber after the current to the carbon had gained a steady value, it was left for a week with the air at atmospheric pressure. The readings taken with the fresh carbon are given in Table X and the readings taken after the fatigued carbon had been left for a week surrounded by air at atmospheric pressure are given in Table XI.

TABLE X.

| Air in apparatus | Fresh carbon electrode. Charge on polonium = 82 volts. | |
|---|---|---|
| Pressure of air in vessel | Time from initial reading taken seven minutes after starting pump | Current to electrode |
| .008 mm. | 0 minutes | 123.5 |
| .003 " | 5 " | 82.5 |
| .001 " | 15 " | 44.5 |
| .001 " | 30 " | 29 |
| < .001 " | 60 " | 22 |
| < .001 " | 90 " | 19.5 |
| < .001 " | 120 " | 18 |
| < .001 " | 142 " | 17.5 |

TABLE XI.

| Fatigued carbon electrode | Air in Apparatus | Charge on polonium = 84 volts |
|---|---|---|
| Pressure of air in vessel | Time from initial reading taken seven minutes after starting pump | Current to electrode. |
| .006 mm. | 0 minutes | 66.3 mms. |
| .004 " | 1 " | 45.3 |
| .002 " | 5 " | 29.3 |
| .002 " | 15 " | 21.3 |
| .001 " | 30 " | 17.3 |

The results given in these two tables are graphically illustrated by the curves shewn in Fig. 6. The upper curve refers to the results in Table X while the lower curve refers to Table XI. A comparison of these curves with the curves shewn in Fig. 4 makes it plain that there was a much greater recovery of the carbon fatigue when it was left *in vacuo* a very short time and then surrounded by air than when it was left for a long time before being surrounded with air.

This pointed to the probability that the gas occluded in the carbon was the cause of the large decrease with the time in the secondary radiation. For if the gas occluded in the carbon, as well as the carbon itself, produced secondary radiation, then, as the exhaustion proceeded gas would ooze out of the carbon and the secondary radiation would decrease until all the gas which could leave had disappeared entirely from the surface of the carbon. Also, the longer the carbon was left *in vacuo* the more occluded gas would come out and the more difficult it would be for the same amount of gas to enter the carbon again. Hence this would cause the fatigue to be more permanent when the carbon was left in a vacuum a long time than when left a short time. This conclusion, it will be seen, has been amply confirmed by the experiment described above.

In order to decide definitely whether the release of the gas occluded in the carbon had to do with the decrease in the secondary rays which has been called a fatigue, a special piece of apparatus was designed and experiments were performed which will be described in the following section.

## VI. EXPERIMENTS SHEWING THE INFLUENCE OF OCCLUDED GAS ON THE SECONDARY RADIATION.

The essential parts of the apparatus (Fig. 7) were two parallel electrodes B and C, in an air tight vessel, separated a distance of about 6 mms.

The polonium which was carried by the electrode B could be made to face in any direction by tunning the axial rod A. This rod passed through and was sealed to a glass tube D which fitted over another glass tube E so arranged that the joint could be covered with mercury and so made air tight. The electrode C which was made of carbon, was connected with the quadrant of an electrometer, the connecting rod passing through an ebonite plug fitted into the side of a vessel by a side tube F. Another side tube G connected the vessel to the McLeod Gauge and the Gaede pump. The vessel itself, which was a cylindrical brass tube about 5 cms. in diameter and 8 cms in length was connected to earth. All joints were made air-tight by means of wax and solder.

The first experiment was conducted as follows. A fresh carbon electrode was placed in the apparatus, the polonium was turned away from the electrode and the air was pumped from the vessel for over an hour with the pump going continuously. Then the polonium was charged to a positive potential of 80 volts and turned so that it faced the carbon electrode. A reading was at once taken of the rate at which the carbon electrode charged up, and similar readings were made at different intervals of time afterwards. The results obtained are given in Table XII.

TABLE XII.

Fresh carbon in apparatus.
Turned polonium to face carbon 1 hour, 20 minutes after pump was started.
Voltage on polonium = 80 volts.

| Pressure of air in vessel | Time from initial reading taken 1 hr, 20 min. after starting pump. | Current to electrode. |
|---|---|---|
| < .001 mm. | 0 minutes | 122 |
| < .001 " | 5 " | 123 |
| < .001 " | 15 " | 124 |
| < .001 " | 30 " | 122 |
| < .001 " | 60 " | 123 |

These results shew that there was no sign of a "fatigue" in the rate at which the carbon electrode charged up with the time, for the rate was practically constant throughout all the readings.

We have seen therefore that it is possible to get rid of the fatigue effect altogether by withdrawing the gas from the surface of the carbon before beginning the bombardment by $\alpha$ rays. The "fatigue" then which has been described in the previous sections must be due to a decrease in the secondary radiation from the gas occluded at the surface of the brass or carbon electrode used.

In view of the effect which the presence of gas has on the secondary radiation it was thought well to repeat the experiment described in Section III and first performed by W. H. Longeman. Instead of using a brass electrode a carbon electrode was used, also the carbon was left in the vessel at low pressure for two days in order that the gas occluded in the carbon should disappear or reach a value which would be constant for the low pressure used. Then readings were taken of the rate at which the carbon electrode charged up as the positive potential on the polonium was varied from 0 volts to about 1700. The results are given in Table XIII below, and a curve drawn from these results is shewn in Fig. 8.

TABLE XIII.

| Voltage on polonium. | Pressure of air in vessel. | Time from initial reading. | Current to electrode. |
|---|---|---|---|
| 0 volts | < .001 mm. | 0 minutes | -447 |
| 1.6 " | " | 12 " | -191 |
| 7 " | " | 16 " | - 4.7 |
| 18 " | " | 28 " | 54 |
| 39 " | " | 31 " | 89 |
| 168 " | " | 38 " | 131 |
| 251 " | " | 44 " | 141 |
| 334 " | " | 48 " | 144 |
| 401 " | " | 62 " | 150 |
| 538 " | " | 72 " | 160 |
| 788 " | " | 95 " | 165 |
| 1095 " | " | 105 " | 172 |
| 1337 " | " | 121 " | 175 |
| 1708 " | " | 137 " | 181 |

The curve shewn in Fig. 8 rises very rapidly from -447 to about 90, as the potential on the polonium was increased from 0 to 40 volts and then more slowly as the potential is increased beyond 40 volts. This is somewhat different from the results obtained in Section III with the brass electrode and shewn graphically in Fig. 2, for the curve in Fig. 2, it will be seen, rises rapidly while the potential on the polonium is raised from 0 to 40 and then falls again as the potential is further increased. The cause of this fall in the rate of charging of the brass electrode as the potential on the polonium was raised above 40 volts in a measure may be attributed, as has been suggested, either to a more profuse reflection of $\alpha$ rays from the electrode as the potential of the polonium was raised or to a gradual decrease in the ionisation current due to a lowering of the

pressure of the air in the apparatus. But as a result of the later experiments performed with the carbon electrode it is clear we must add another and more important cause for the fall, namely, the decrease in the secondary radiation throughout the experiment as the gas layer on the electrode became less and less dense.

The experiment just described with the carbon electrode shews that when the gas layer was removed, there was no fall in the rate of charging of the carbon electrode, as the potential on the polonium was increased, but, instead a gradual increase was obtained.

The question arose, then, whether the brass electrode would act in the same manner as the carbon electrode if the gas layer was first removed from it. To answer this question the brass electrode was kept *in vacuo* a long time and the experiment with it was repeated. Contrary to expectation it was found that there was still a very slight decrease in the rate of charging of the electrode after the potential of the polonium was raised above 40 volts but this decrease was not nearly as great as before.

The reason for the final slight difference between the behaviour of a carbon and of a brass electrode appears then to be due to a difference between the $\alpha$ ray reflecting power of carbon and brass at different voltages, the brass reflecting more $\alpha$ rays than the carbon as the voltage was increased.

If the work done by Geiger and Marsden*[1] on the reflection of $\alpha$ rays is taken to be applicable to the present experiments, it would seem that $\alpha$ particles can not be reflected in sufficient numbers to account for this difference. However, the experiments described above point definitely to the reflection of $\alpha$ rays as the cause of the slight difference in the behaviour of the carbon and the brass plates under the bombardment by $\alpha$ rays. Moreover, it can easily be shewn that with the fields used variations in the speed of the $\alpha$ rays amounting to 1.7% must ensue. It is just possible that this variation might be sufficient to cause such a change in the amount of $\alpha$ radiation reflected from the carbon and brass electrodes as to contribute, in part at least, to the above effect. It would appear, therefore, that additional experiments should be made on the reflection of $\alpha$ rays of different velocities at surfaces subjected to low gas pressures before the explanation offered above of the effect observed is set aside.

## VII. SUMMARY OF RESULTS.

1. It has been shewn that there is a secondary radiation produced when alpha rays fall on a brass or a carbon plate.

*[1] Geiger and Marsden, Proc. Roy. Soc. Ser. A, 82 July 31, 1909.

2. This secondary radiation has been proved to be in part due to the presence of gas occluded in or at the surface of the brass or carbon.

3. When this gas is being removed from the brass or carbon it is found that the secondary radiation decreases and gives rise to an effect similar to a "fatigue" of the secondary rays.

4. This fatigue effect is found to be greater for carbon than for brass. This last result was to be expected when the fatigue effect was traced to the presence of occluded gases since carbon is known to possess a greater capacity for occluding gases than a metal such as brass.

5. From the experiments which have been described it will be seen that the secondary radiation emitted by a substance like carbon under bombardment by $\alpha$ rays furnishes a new means of investigating the process by which gases are occluded in carbon and probably also in other substances.

In conclusion I wish to express my gratitude to Professor McLennan for his suggestions and help throughout the course of this investigation.

Physical Laboratory,
University of Toronto.

FIGURE 1.

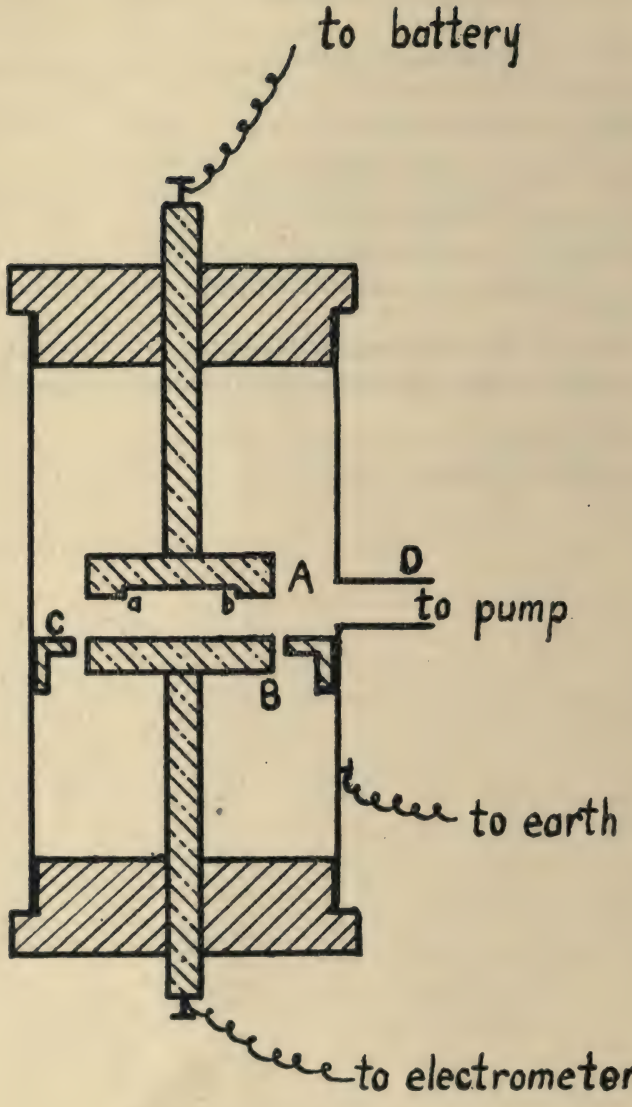
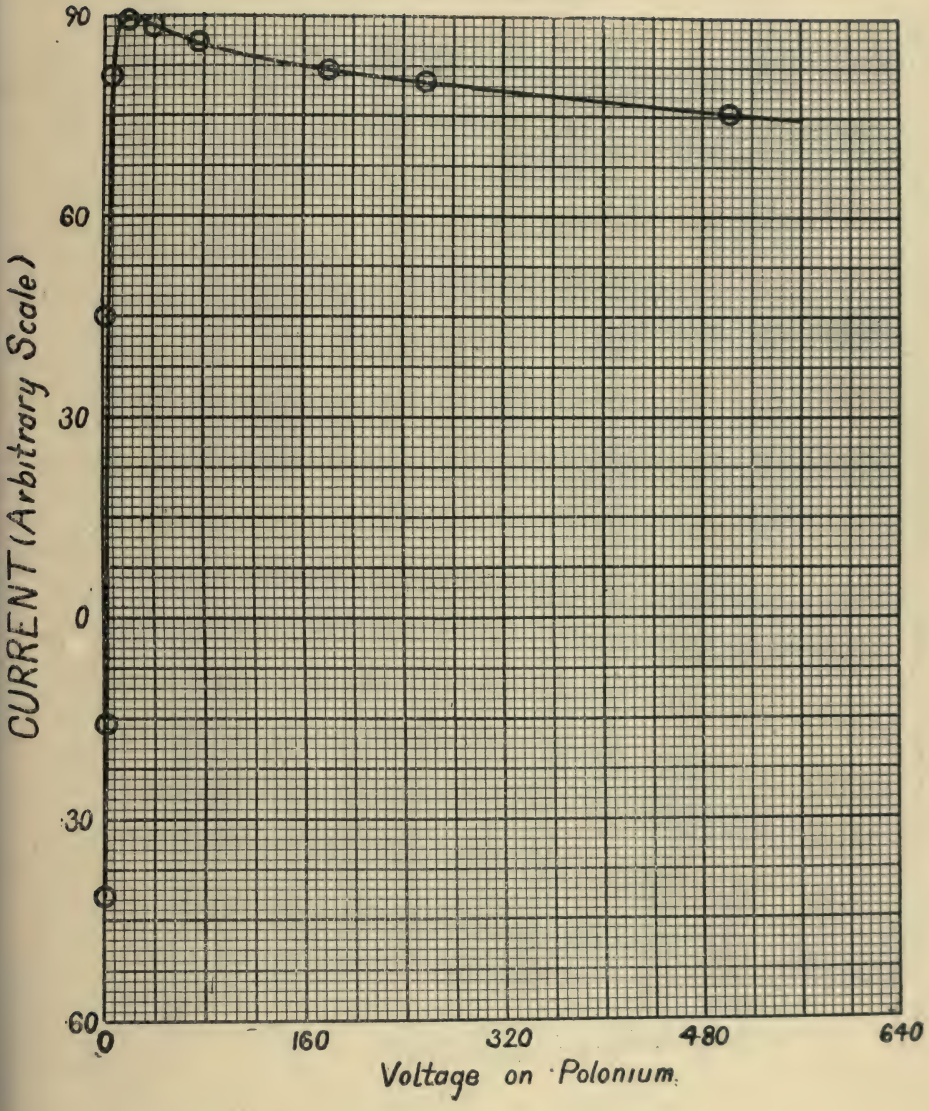


FIGURE 2.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30
0
30
60
CURRENT (Arbitrary Scale)
0
160
320
480
640
Voltage on Polonium

FIGURE 3.

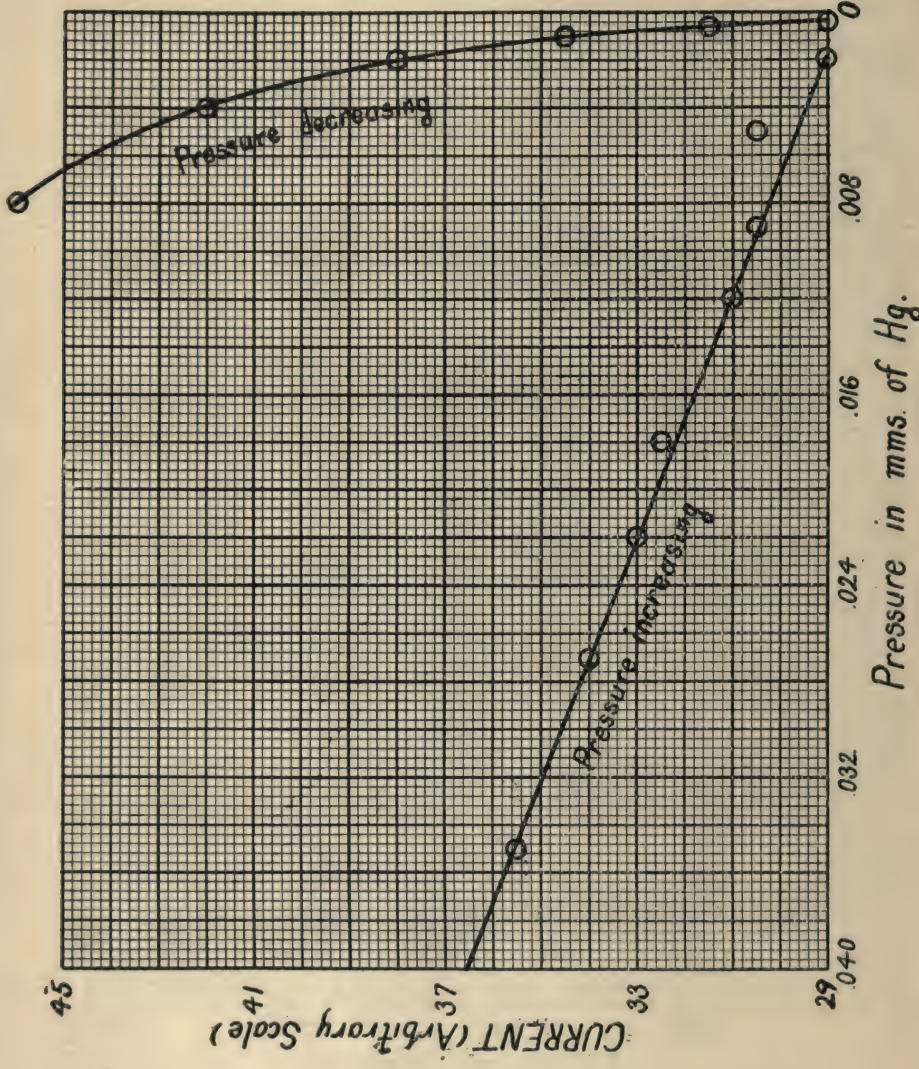
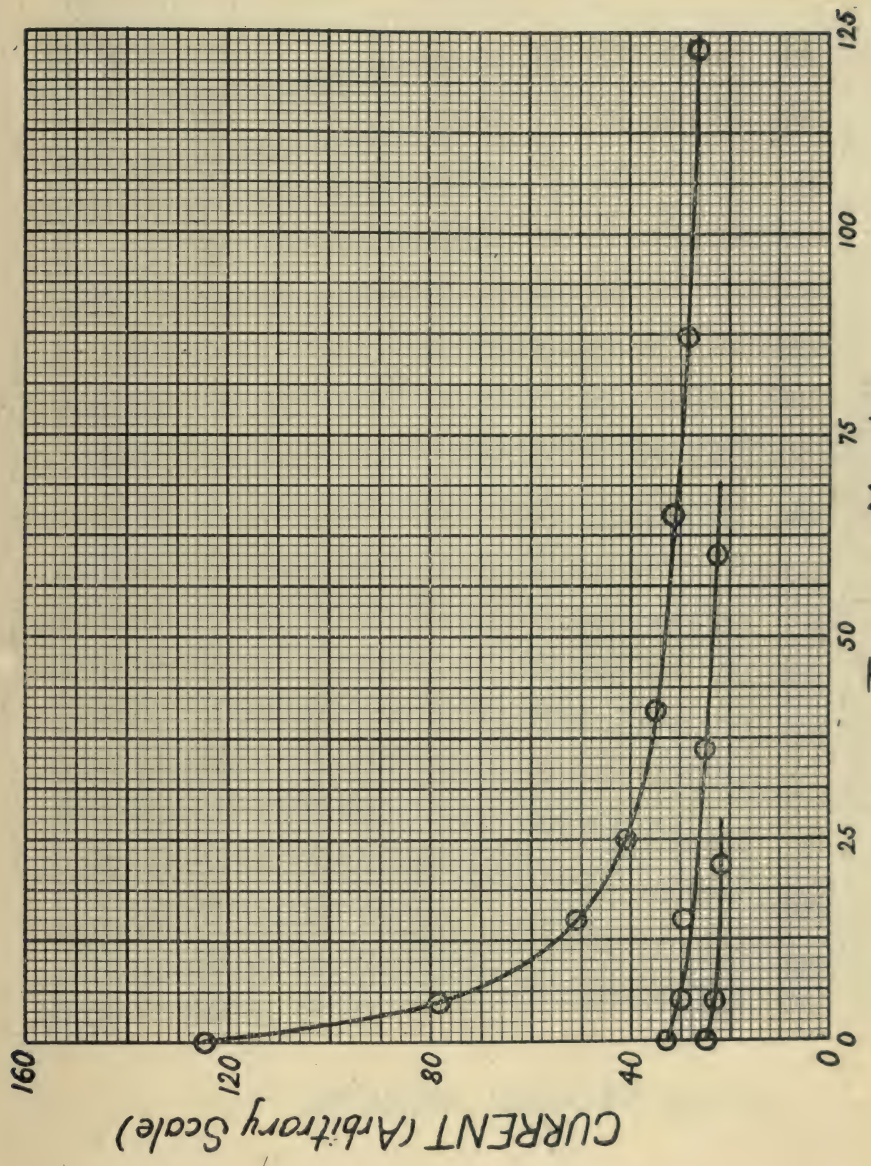

Pressure decreasing
Pressure increasing
0
.008
.016
.024
.032
.040
Pressure in mms. of Hg.
45
41
37
33
29
CURRENT (Arbitrary Scale)

FIGURE 4.


CURRENT (Arbitrary Scale)
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120
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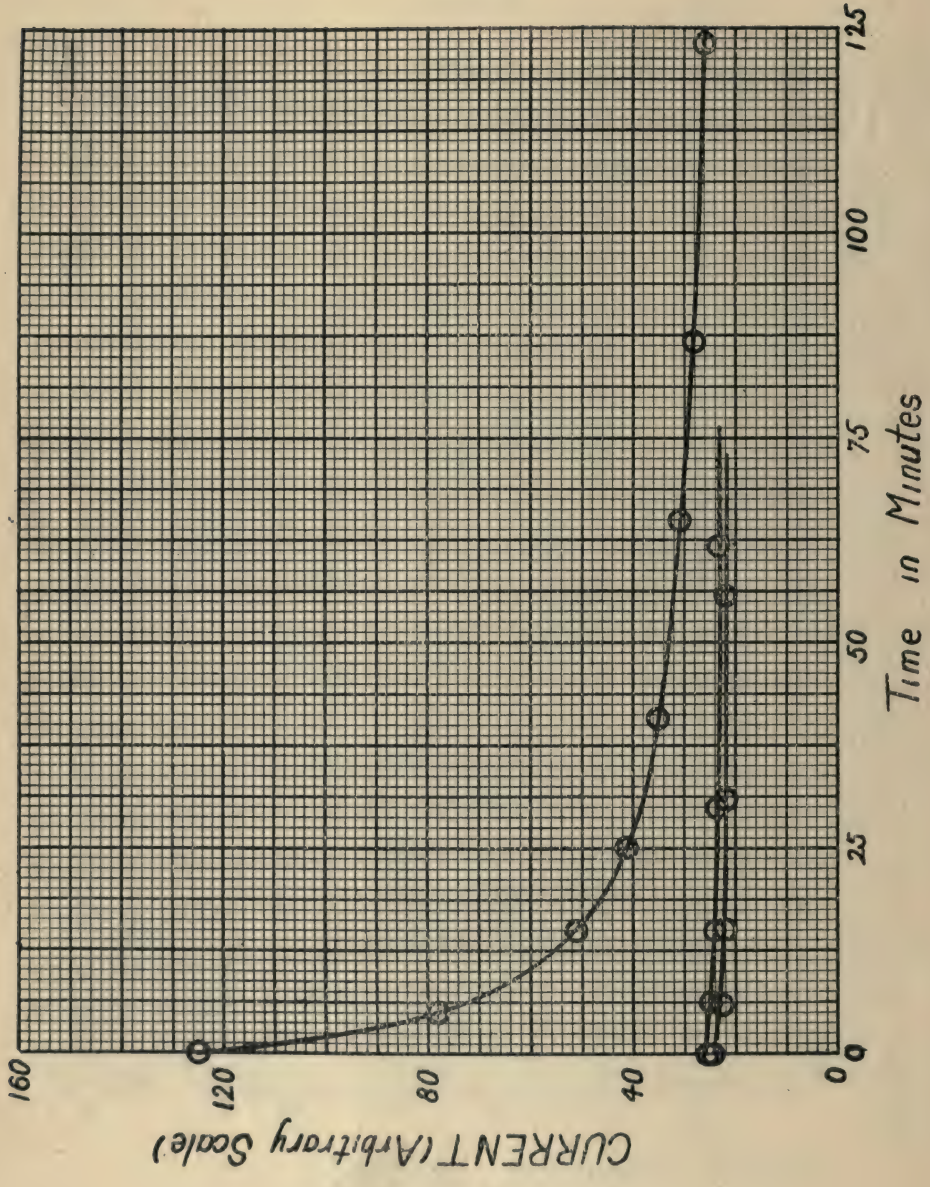
40
0
0
25
50
75
100
125
Time in Minutes.

FIGURE 5.


CURRENT (Arbitrary Scale)
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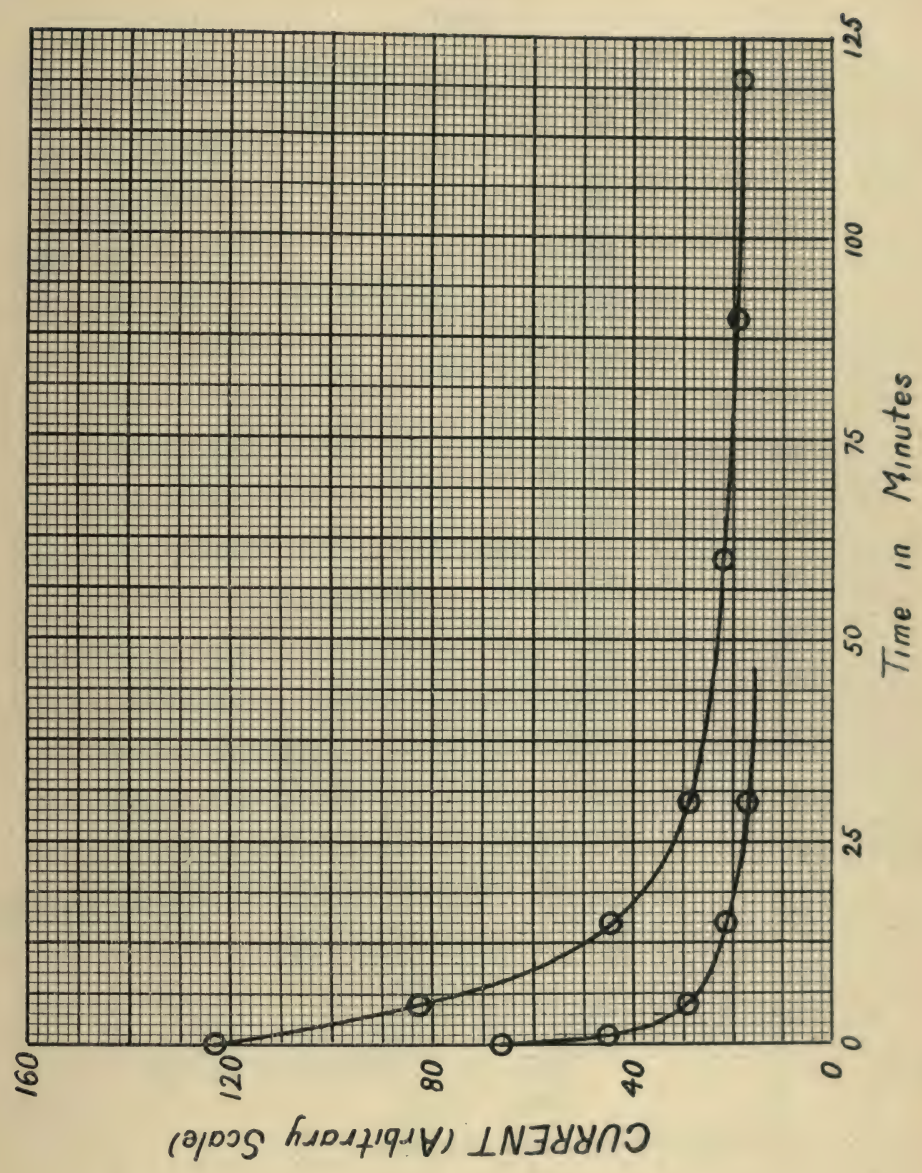
0
25
50
75
100
125
Time in Minutes

FIGURE 6.


CURRENT (Arbitrary Scale)
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120
80
40
0
0
25
50
75
100
125
Time in Minutes

FIGURE 7.

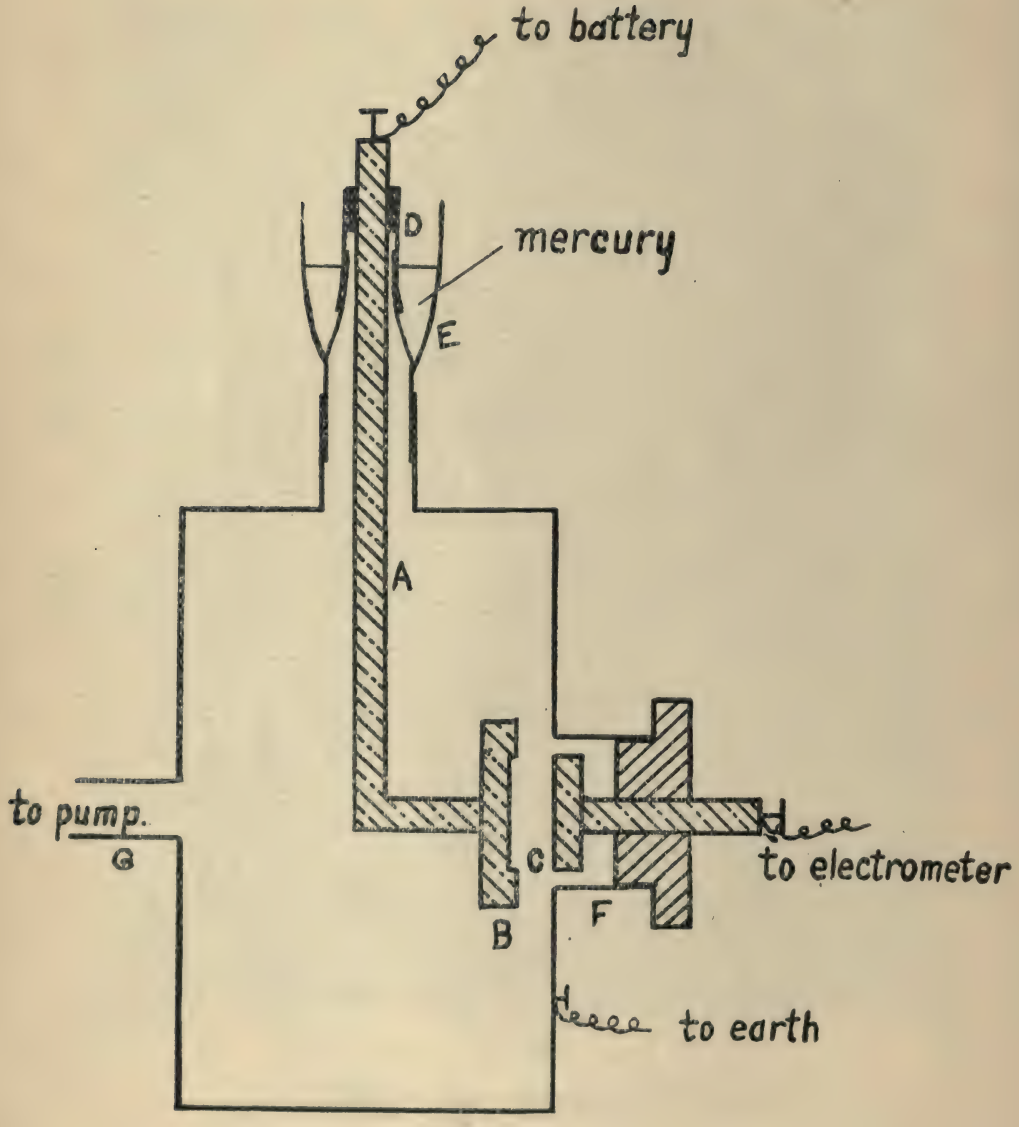
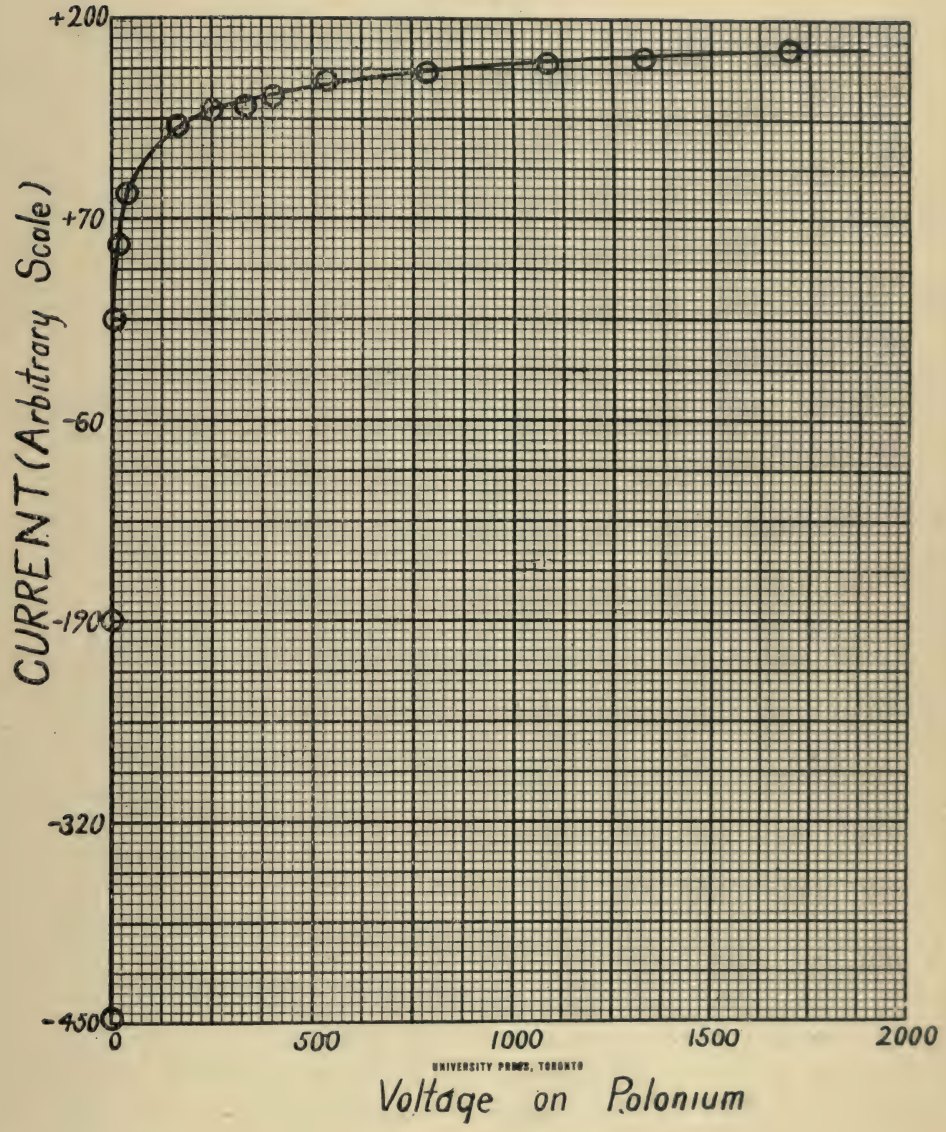

to battery
D
mercury
E
A
to pump.
G
C
B
F
to electrometer
to earth

FIGURE 8.


+200
+70
-60
-190
-320
-450
CURRENT (Arbitrary Scale)
0
500
1000
1500
2000
UNIVERSITY PRESS, TORONTO
Voltage on Polonium

# ON THE SECONDARY RAYS EXCITED BY THE ALPHA RAYS FROM POLONIUM—II.

(*Read 13th January, 1912*).

BY V. E. POUND, M.A.*

## I.—INTRODUCTION.

In a previous paper by the writer*[1] it has been shewn that when the $\alpha$ rays of polonium strike a carbon or a brass plate, secondary rays are produced which are similar to the $\delta$ rays of polonium. It has been shewn, too, that a very considerable part of this secondary radiation is due to the presence of gas occluded at or deposited on the surface of the brass or carbon plate. The present paper describes some further experiments on the influence of this gaseous layer on the secondary radiation excited in different substances when these are subjected to bombardment by the $\alpha$ rays of polonium.

## II.—DESCRIPTION OF APPARATUS.

The apparatus used for the investigation was composed of a brass tube A about 3 cm. in diameter and 18 cm. long, one end of which was closed air tight by an ebonite plug sealed in with wax. Centrally through this plug was led a brass rod, B, carrying a brass plate C upon which a thin circular piece of polonium coated brass about 1.5 cm. in diameter was fixed. A brass ring D passed through the ebonite and connected to earth served as a guard ring. At the other end of the tube A, a smaller tube E, 1.5 cm. in diameter was inserted and soldered in position at the top so as to be co-axial with the former. In this way the space between the tubes A and E was made air tight. The lower end of the tube E was closed by means of a very thin brass sheet and a flat circular plate K of carbon or metal was held against this thin brass sheet by means of a flanged collar F provided with a screw. The distance between the polonium and the lower face of the carbon or brass plate was .6 cm. The whole apparatus was connected by a tube G to a Gaede pump and a McLeod gauge. The apparatus was insulated by mica and supported in such a way that the polonium and the circular plate

*Presented by Prof. J. C. McLennan.

*[1]Trans. Canadian Institute, 1912.

opposite the polonium were symmetrically placed between the poles of a powerful electromagnet. The circular plate held at F could be altered in temperature by liquid air or some other liquid of constant temperature in the tube E. The polonium was connected by means of the brass rod B and a screened connecting wire to an electrometer of moderate sensibility.

III.—EXPERIMENTS WITH CARBON AT DIFFERENT TEMPERATURES.

The method of conducting the experiments was as follows. The carbon plate K was charged to a negative potential of about 80 volts by connecting the outer part of the apparatus to a battery. This high negative potential on the carbon was sufficient to prevent any $\delta$ rays from leaving the polonium. The Gaede pump was set exhausting the gas from the apparatus and seven minutes after the pump was started the pressure of the gas was read by a McLeod Gauge and the rate of charging of the polonium was measured by the electrometer. The charge which came to the polonium was negative and consisted of a current of $\alpha$ rays leaving the polonium, a current of secondary rays coming from the carbon to the polonium excited by the $\alpha$ ray bombardment on the carbon, and an ionisation current through the remaining gas in the chamber. Readings of the charge which accrued on the polonium plate were made at definite intervals of time afterwards until the rate of charging of the plate became fairly constant. This constant value as shewn in the previous paper* was reached when the density of the layer of gas occluded in the surface of the carbon was in equilibrium with the pressure of gas in the vessel, that is, when there was no readjustment going on in the gaseous layer. After the rate of charging of the polonium had become fairly constant a weak magnetic field was established by passing a small current through the electromagnet, and the rate of charging of the polonium was again found. Then larger and larger currents were sent through the electromagnet and readings were taken until the rate of charging of the polonium became constant. This last constant charge which came to the polonium was composed of the $\alpha$ ray current leaving the polonium and the ionisation current through the gas. The magnetic field was used to deflect the slow moving secondary rays coming from the carbon and the constant rate of charging of the polonium denoted that the magnetic field had deflected them all. The influence of the magnetic field in deflecting the $\alpha$ rays or the ionisation current through the gas was probably very small. Accordingly the difference between the first constant value of the rate of charging of the polonium and the last constant value was a

*Trans. Canadian Institute, 1912.
Phil. Mag. 1912.

measure of the magnitude of the secondary ray current from the carbon excited by the α ray bombardment.

In the following tables the results obtained with air filled carbon, first at a temperature of 110° C, second at room temperature, third at a temperature given by a mixture of solid carbonic acid gas and ether, namely, −78° C, and lastly at liquid air temperature, −192° C are given. After each experiment air was allowed to remain in the apparatus at atmospheric pressure until the next experiment. Before beginning the set of experiments a piece of carbon, the surface of which was freshly cut and which had never before been exposed to α rays was placed in the apparatus. For comparison all the readings were reduced to the same date by the use of the standard equation,

$$I = I_o e^{-\lambda t}$$

the half decay period of the polonium being taken as 140 days.*

TABLE I.—AIR IN APPARATUS.

Carbon electrode at temperature 110°C. Charge on carbon = −83 volts.

| Pressure of air in vessel. | Time from initial reading taken 7 min. after starting pump. | Current through magnet. | Current to Polonium. |
|---|---|---|---|
| .02 mm. | 0 min. | 0 amp. | −203 |
| .007 " | 5 " | 0 " | −185 |
| .007 " | 15 " | 0 " | −173 |
| .004 " | 30 " | 0 " | −169 |
| .003 " | 45 " | 0 " | −162 |
| .006 " | 60 " | 0 " | −166 |
| .003 " | 68 " | 0 " | −162.5 |
| .005 " | 90 " | 0 " | −162 |
| .004 " | .. | 1 " | − 98 |
| .002 " | .. | 6 " | − 41 |
| .002 " | .. | 15 " | − 39.2 |
| .002 " | .. | 23.5 " | − 37.8 |

*See Physical and Chemical Constants by Kaye and Laby, page 107.

TABLE II.—AIR IN APPARATUS.

Carbon electrode at temp. 23° C. Charge on Carbon = −83 volts.

| Pressure of air in vessel. | Time from initial reading taken 7 mins. after starting pump. | Current through magnet | Current to polonium |
|---|---|---|---|
| .02 mm. | 0 min. | 0 amp. | −254 |
| .006 " | 5 " | 0 " | −209.5 |
| .003 " | 15 " | 0 " | −180 |
| .003 " | 30 " | 0 " | −165 |
| .002 " | 45 " | 0 " | −158 |
| .002 " | 60 " | 0 " | −158 |
| .002 " | .. | 1 " | − 57.8 |
| .002 " | .. | 5.5 " | − 38 |
| .002 " | .. | 12 " | − 37.4 |
| .002 " | .. | 18.5 " | − 37.4 |
| .002 " | .. | 26 " | − 37.4 |

TABLE III.—AIR IN APPARATUS.

Carbon electrode at temp. −78° C. Charge on carbon = −84 volts.

| Pressure of air in vessel. | Time from initial reading taken 7 mins. after starting pump. | Current through magnet | Current to polonium. |
|---|---|---|---|
| .02 mm. | 0 min. | 0 amp. | −161.5 |
| .004 " | 5 " | 0 " | −157.7 |
| .003 " | 15 " | 0 " | −159.2 |
| .001 " | 30 " | 0 " | −161.5 |
| .001 " | 45 " | 0 " | −165 |
| .001 " | 70 " | 0 " | −172 |
| .001 " | 90 " | 0 " | −176 |
| less than .001 " | 105 " | 0 " | −178 |
| " .001 " | 140 " | 0 " | −182 |
| " .001 " | 155 " | 0 " | −184 |
| " .001 " | ... | 1 " | − 36.5 |
| " .001 " | ... | 6 " | − 35 |
| " .001 " | ... | 11 " | − 35 |
| " "001 . | ... | 17.5 " | − 33 |
| " .001 " | ... | 24 " | − 35 |

TABLE IV.—AIR IN APPARATUS.

Carbon electrode at temp. −192° C. Charge on Carbon = −84 volts.

| Pressure of air in vessel. | Time from initial reading taken 7 mins. after starting pump. | Current through magnet. | Current to polonium. |
|---|---|---|---|
| .03 mm. | 0 min. | 0 amp. | −269 |
| .009 " | 5 " | 0 " | −245 |
| .004 " | 15 " | 0 " | −246 |
| .004 " | 25 " | 0 " | −245 |
| .002 " | 40 " | 0 " | −249 |
| .002 " | 55 " | 0 " | −252 |
| .002 " | 70 " | 0 " | −253.8 |
| .001 " | 85 " | 0 " | −256 |
| .001 " | 100 " | 0 " | −262 |
| .001 " | 118 " | 0 " | −262 |
| .001 " | ... | 1 " | − 37 |
| .001 " | ... | 5.5 " | − 35 |
| .001 " | ... | 11 " | − 34 |
| .001 " | ... | 16.5 " | − 34 |
| .001 " | ... | 24.5 " | − 34.4 |

The results given in these tables are plotted in Figures (1), (2), (3) and (4). The curve drawn on the first half of each figure shews the way the rate of charging of the polonium decreased or increased with the time until it became approximately constant. The curve drawn on the remaining half of the figure shews the way the rate of charging of the polonium decreased to a constant value as the magnetic field was gradually increased from zero upwards. The curves drawn on the first half of Fig. (3) and of Fig. (4) shew a remarkable difference from the corresponding curves in Figures (1) and (2). The curves of Figures (1) and (2) drop gradually with the time and come to a constant value while the curves of Figures (3) and (4) first decrease and then increase to an approximately constant value. The only difference in the conditions under which the experiments were made was a difference in the temperature of the carbon. When the carbon was at room temperature or at a temperature of 110° C, the rate of charging of the polonium decreased with the time before becoming constant while when the carbon was at −78° C or at -192° C the rate of charging decreased slightly and then increased. The cause of this difference is readily seen when it is remember-

ed that carbon occludes more air at a low temperature than at a high and that the α rays excite secondary in the air layer on the surface of the carbon as well as in the carbon itself.* When the temperature of the carbon is high the air readily comes away from the surface of the carbon and hence the secondary radiation decreases. When the temperature of the carbon is low the air does not come away but becomes denser and denser at the surface of the carbon as it oozes out of the interior and also as it comes out of the cooled brass walls of the apparatus. (It will be shewn later that air is expelled from brass as it is cooled.) Therefore instead of a decrease there is set up a gradual increase in the secondary radiation as the air layer becomes denser.

The final value of the secondary radiation from the carbon and the air layer at its surface was obtained in each case by taking the difference between the constant rates of charging of the polonium without and with the applied magnetic field. In the following table the values of the secondary radiation with the carbon at the several different temperatures are set down.

TABLE V.—FRESH CARBON IN AIR.
Secondary radiation from Carbon and Air Layer.

| Temperature of Carbon... | 110°C | 23°C | −78°C | −192°C |
|---|---|---|---|---|
| Secondary Radiation..... | −124.5 | −120.6 | −151 | −228 |

It will be seen from the table that when the carbon was at the temperature of 23° C the secondary radiation excited by the α rays was -120.6 and when the carbon was at 110° C the secondary radiation was -124.5. These numbers are very nearly the same and accounting for their difference by experimental error, they shew that the amount of α ray excited secondary radiation from carbon was the same when the carbon was at 23° C as when it was at 110° C. Since this secondary radiation most probably comes from both the carbon and its air layer, the co-incident values of the secondary radiation from carbon at the two temperatures would indicate that the density of the gaseous layer at the surface of the carbon was the same at the two temperatures. When the carbon was at −78° C however, the secondary radiation from it amounted to -151 i.e., an increase of about 24% over the value of the secondary radiation when the carbon was at room temperature. Again when the carbon was at −192° C the secondary radiation was −228 or an increase of 87% above the value at room temperature. These large

*V. E. Pound, Trans. Canadian Institute, 1912.
Phil. Mag. 1912.

increases in the secondary radiation when the carbon was at the lower temperatures is readily accounted for by the increase in the secondary radiation from the gaseous air layer at the surface of the carbon which increases in density as the temperature is lowered.

In order to find out whether this same effect would occur when the carbon was in other gases than air, experiments were also tried with oxygen and hydrogen. A fresh piece of carbon was used for each gas. The air which was occluded in the fresh piece of carbon on account of its being in an atmosphere of air was got rid of by putting the carbon in the apparatus and exhausting and leaving it for a long time. The apparatus was then filled with the gas which was to be experimented upon and left for some time in order that the carbon might take up the new gas as much as possible. After this the carbon was cooled or heated to the desired temperature, the gas was pumped from the apparatus and a series of readings was taken, in the manner indicated above, of the rate of charging of the polonium both with and without the magnetic field. The same characteristic results were obtained with these gases at the different temperatures as with the air. The readings taken with the carbon at temperatures 115° C, 23° C, -78° C and -192° C in an atmosphere of oxygen are given in Tables VI, VII, VIII and IX below and the readings taken with the carbon at temperatures 24° C and -192° C in an atmosphere of hydrogen are given in Tables X and XI.

TABLE VI.—OXYGEN IN APPARATUS,

Carbon electrode at temp. 115° C. Charge on carbon = −84 volts

| Pressure of air in vessel | Time from initial reading 7 mins. after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .05 mm. | 0 min. | 0 amp. | −219.5 |
| .012 " | 5 " | 0 " | −199.5 |
| .008 " | 15 " | 0 " | −189.5 |
| .005 " | 25 " | 0 " | −182 |
| .003 " | 102 " | 0 " | −157 |
| .001 " | 114 " | 0 " | −157 |
| less than .001 " | 130 " | 0 " | −158 |
| " .001 " | 133 " | 0 " | −158 |
| " .001 " | ... | 1 " | − 42 |
| " .001 " | ... | 9 " | − 34.3 |
| " .001 " | ... | 15 " | − 32.8 |
| " .001 " | ... | 23.5 " | − 32.8 |

TABLE VII.— OXYGEN IN APPARATUS.

Carbon Electrode at Temp. 23° C. Charge on Carbon = −84 volts.

| Pressure of air in vessel | Time from initial reading 7 min. after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .06 mm. | 0 min. | 0 amp. | −184 |
| .015 " | 5 " | 0 " | −175 |
| .006 " | 15 " | 0 " | −159 |
| .003 " | 30 " | 0 " | −156 |
| .003 " | 40 " | 0 " | −156 |
| .001 " | 55 " | 0 " | −155 |
| .001 " | 70 " | 0 " | −155 |
| .001 " | 86 " | 0 " | −155 |
| .001 " | ... | 1 " | − 38 |
| .001 " | ... | 5.5 " | − 34 |
| .001 " | ... | 12 " | − 34 |
| .001 " | ... | 20 " | − 32 |
| .001 " | ... | 25 " | − 34 |

TABLE VIII.—OXYGEN IN APPARATUS.

Carbon electrode at Temp. −78° C. Charge on carbon = −83 volts.

| Pressure of air in apparatus | Time from initial reading 7 minutes after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .045 mm. | 0 min. | 0 amp. | −206.5 |
| .011 " | 5 " | 0 " | −190 |
| .005 " | 15 " | 0 " | −187 |
| .003 " | 30 " | 0 " | −185.5 |
| .003 " | 45 " | 0 " | −188 |
| .003 " | 60 " | 0 " | −187 |
| .002 " | 75 " | 0 " | −188 |
| .002 " | 90 " | 0 " | −190 |
| .002 " | 128 " | 0 " | −193.5 |
| .002 " | 132 " | 0 " | −193.5 |
| .002 " | ... | 1 " | − 36.2 |
| .002 " | ... | 12 " | − 34.2 |
| .002 " | ... | 18 " | − 34.2 |
| .002 " | ... | 25 " | − 33.4 |

## TABLE IX.—OXYGEN IN APPARATUS.

Carbon electrode at Temp. -192° C. Charge on carbon = −84 volts.

| Pressure of air in apparatus | Time from initial reading 7 minutes after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .08 mm. | 0 min. | 0 amp. | −277 |
| .012 " | 5 " | 0 " | −237 |
| .006 " | 15 " | 0 " | −224.5 |
| .004 " | 30 " | 0 " | −224.5 |
| .004 " | 45 " | 0 " | −229 |
| .003 " | 60 " | 0 " | −224.5 |
| .003 " | 75 " | 0 " | −227.5 |
| .003 " | 90 " | 0 " | −225 |
| .003 " | ... | 1 " | − 35.5 |
| .003 " | ... | 5 " | − 33.4 |
| .002 " | ... | 13 " | − 32.6 |
| .003 " | ... | 19 " | − 33.4 |
| .002 " | ... | 24.5 " | − 33.4 |

## TABLE X.—HYDROGEN IN APPARATUS

Carbon Electrode at Temp. 24° C. Charge on Carbon = −84 volts.

| Pressure of air in apparatus | Time from initial reading 7 minutes after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .006 mm. | 0 min. | 0 amp. | −429.5 |
| .002 " | 10 " | 0 " | −230.5 |
| .001 " | 20 " | 0 " | −205 |
| less than .001 " | 40 " | 0 " | −202 |
| " .001 " | 60 " | 0 " | −196 |
| " .001 " | 90 " | 0 " | −194 |
| " .001 " | ... | 1.5 " | − 66 |
| " .001 " | ... | 4.5 " | − 47.5 |
| " .001 " | ... | 9 " | − 48.5 |
| " .001 " | ... | 18 " | − 49 |
| " .001 " | ... | 24.5 " | − 47 |

TABLE XI.—HYDROGEN IN APPARATUS.

Carbon electrode at Temp.–192° C. Charge on carbon = –84 volts.

| Pressure of air in apparatus | Time from initial reading 7 minutes after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| .015 mm | 0 min. | 0 amp. | –256 |
| .004 " | 5 " | 0 " | –212 |
| .002 " | 22 " | 0 " | –213 |
| .001 " | 29 " | 0 " | –227.5 |
| .001 " | 39 " | 0 " | –238 |
| less than .001 " | 52 " | 0 " | –242 |
| " .001 " | 65 " | 0 " | –254 |
| " .001 " | 80 " | 0 " | –249 |
| " .001 " | 95 " | 0 " | –266 |
| " .001 " | 115 " | 0 " | –272 |
| " .001 " | 130 " | 0 " | –273 |
| " .001 " | ... | 1.5 " | – 39.6 |
| " .001 " | ... | 4 " | – 37.5 |
| " .001 " | ... | 9.5 " | – 36.8 |
| " .001 " | ... | 15.5 " | – 36.8 |
| " .001 " | ... | 25 " | – 36.2 |

From these results the values of the secondary radiation from the carbon at different temperatures in oxygen and in hydrogen were deduced as with the air, by taking the difference between the final rates of charging of the polonium without and with the magnetic field applied. These are given in Tables XII. and XIII.

TABLE XII.—FRESH CARBON IN OXYGEN

Secondary Radiation from Carbon and Oxygen Layer.

| Temperature of Carbon... | 115° | 23° | –78° | –192° |
|---|---|---|---|---|
| Secondary Radiation..... | –124.7 | –121.5 | –160 | –193 |

TABLE XIII.—FRESH CARBON IN HYDROGEN.

Secondary Radiation from Carbon and Hydrogen Layer.

| Temperature of Carbon... | 24° C | –192° C |
|---|---|---|
| Secondary Radiation..... | –147 | –236 |

Here again we find that both with oxygen and with hydrogen the results shew that the secondary radiation was much greater when the

carbon was at a low temperature than when it was maintained at a higher temperature.

From the foregoing it is clear that this modification of the intensity of the secondary radiation is attributable as in the case of air to an increase in the amount of gaseous oxygen and hydrogen occluded in the surface of the carbon by a reduction of the temperature.

From the experiments just described it follows that the amount of secondary radiation obtained from an electrode under bombardment by $\alpha$ rays may be taken as a measure of the density of the gaseous layer at the surface of the electrode when the latter is placed in a gas at a very low pressure. If there were no difference in the secondary radiation from a substance at different temperatures under the conditions mentioned it would indicate either that there was no gaseous layer at the surface of the substance bombarded, or else that the density of the gaseous layer adhering to it was the same at all temperatures. In the following section an experiment is described which makes use of this conclusion.

## IV.—EXPERIMENTS WITH BRASS.

A peculiar effect was observed during the course of all the experiments, namely, that it took a longer time to reduce the pressure of the gas in the apparatus to a low value when the walls of the vessel were cooled with liquid air, than when the walls were at ordinary room temperature. At first this effect was supposed to be due to some leak in the apparatus and the vessel was removed and carefully tested under pressure for small holes or porous places in the brass. But invariably it was found that no such holes or porous places could be discovered. It was also found that when the apparatus was put back and exhausted at ordinary temperatures the pressure was reduced with the same speed as before the apparatus was cooled with liquid air. There seemed, therefore, to be no leak of air through the walls of the apparatus and the only other explanation that could be offered was that a gas came from the walls of the brass vessel at liquid air temperature which did not come at room temperature. If this were the case there would be less gas in the brass at low temperature than at high, and the method indicated in the previous section of studying the gaseous layer at the surface of a substance by the quantity of secondary rays coming from it could be used to test the above explanation. Accordingly a brass plate was placed at K instead of a carbon one and the amount of $\alpha$ ray excited secondary radiation from the brass plate was determined when it was at room temperature, and when it was at the temperature of liquid air. The series of readings taken are given in Tables XIV and XV. In order that the brass when at room temperature might be as free of air as possible the pump was made

to exhaust the air from the apparatus for three hours continuously before a reading was taken of the rate of charging of the polonium.

TABLE XIV.—AIR IN APPARATUS.

Brass electrode at Temp. 20° C. Charge on brass = −81 volts.

| Pressure of air in apparatus | Time from initial reading 3 hours after starting pump | Current through magnet | Current to polonium |
|---|---|---|---|
| less than .001 mms. | 0 min. | 0 amp. | −238.5 |
| " .001 " | 5 " | 0 " | −237 |
| " .001 " | 15 " | 0 " | −238.5 |
| " .001 " | .. | 1 " | − 40.5 |
| " .001 " | .. | 10 " | − 34.5 |
| " .001 " | .. | 17 " | − 34 |
| " .001 " | .. | 22 " | − 34.5 |

It will be seen from the above table that at the end of three hours constant pumping by the Gaede pump the pressure of the air in the apparatus had fallen very low and that the rate of charging of the polonium had become constant before the magnetic field was applied.

Immediately after the readings on the rate of charging of the polonium with increasing magnetic fields were taken, another reading was taken of the rate of charging of the polonium without the magnetic field. After this the brass plate was cooled by pouring liquid air in the tube E, and the readings on the rate of charging of the polonium were continued once more.

TABLE XV.—AIR IN APPARATUS.

Brass Electrode. Charge on Brass = −81 volts.

| Pressure of air in apparatus | Time ftom initial reading of Table XIV | Current through magnet | Current to polonium |
|---|---|---|---|
| Less than .001 mm. | 28 min. | 0 amp. | −238.5 |
| | COOLED BRASS WITH LIQUID AIR. | | |
| .003 mm. | 35 min. | 0 amp. | −235.5 |
| .005 " | 40 " | 0 " | −227 |
| .005 " | 50 " | 0 " | −217 |
| .005 " | 65 " | 0 " | −214 |
| .004 " | 80 " | 0 " | −210.5 |
| .004 " | 95 " | 0 " | −210.5 |
| .004 " | 110 " | 0 " | −210.5 |
| .003 " | 140 " | 0 " | −209 |
| .003 " | 170 " | 0 " | −210.5 |
| .003 " | ... | 1 " | − 42.5 |
| .003 " | ... | 9.5 " | − 35.6 |
| .003 " | ... | 16 " | − 35.6 |
| .003 " | ... | 21.5 " | − 36.5 |

From the numbers given in the table it will be seen that immediately after the brass began to cool down to the temperature of the liquid air the pressure in the apparatus rose slightly and then fell again as the pumping was continued. The rate at which the polonium charged up, however, steadily decreased as the brass plate cooled down. As the effect of a rise in pressure would be to increase the ionisation current in the chamber it follows from the occurrence of this decrease in the rate of charging of the polonium that the secondary radiation from the brass plate must have dropped off as its temperature lowered.

The values of the $\alpha$ ray excited secondary radiation from the brass plate at temperatures 20° C and -192° C as deduced from Tables XIV and XV are given in Table XVI.

TABLE XVI.—BRASS IN AIR.

Secondary Radiation from Brass and Air Layer.

| Temperature of Brass.... | 20° C | −192° C |
|---|---|---|
| Secondary Radiation..... | −215 | −173 |

From these numbers it is evident that the secondary radiation from the brass at a temperature of 20° C was about 25% higher than it was under the same $\alpha$ ray bombardment at the temperature of liquid air.

If differences in $\alpha$ ray excited secondary radiation at low pressures be taken to connote differences in the quantities of gas occluded at the surface of the substance bombarded, the meaning of this smaller secondary radiation from the brass at liquid air temperature is that the brass held less gas in its surface at liquid air temperature than at the temperature of the room. This experiment therefore, strongly supports the explanation given above of the greater difficulty experienced in pumping the air from the brass chamber at -192° C than in making the same exhaustion when the apparatus was maintained at the temperature of the room.

## V.—SUMMARY OF RESULTS.

I. The secondary radiation excited by the $\alpha$ rays of polonium in carbon was found to increase in intensity as the temperature of the carbon was lowered from room temperature to the temperature of liquid air.

II. This increase in the secondary radiation from carbon as its temperature was lowered has been shewn to be due to an increase in the amount of gas occluded in the surface of the carbon.

III. Since it has been shewn that gases occluded in such substances as carbon contribute to the secondary radiation excited at the surface of these substances by $\alpha$ rays, it follows that the procedure adopted in this investigation constitutes a new method of studying the phenomena of occlusion.

IV. The results of the experiments described in this paper also go to shew that with a metal like brass the amount of a gas retained in its surface when it is placed in a vacum is less at the temperature of liquid air than at ordinary room temperature.

In conclusion, I desire to thank Professor McLennan for the kindly interest he has shewn throughout the course of this research.

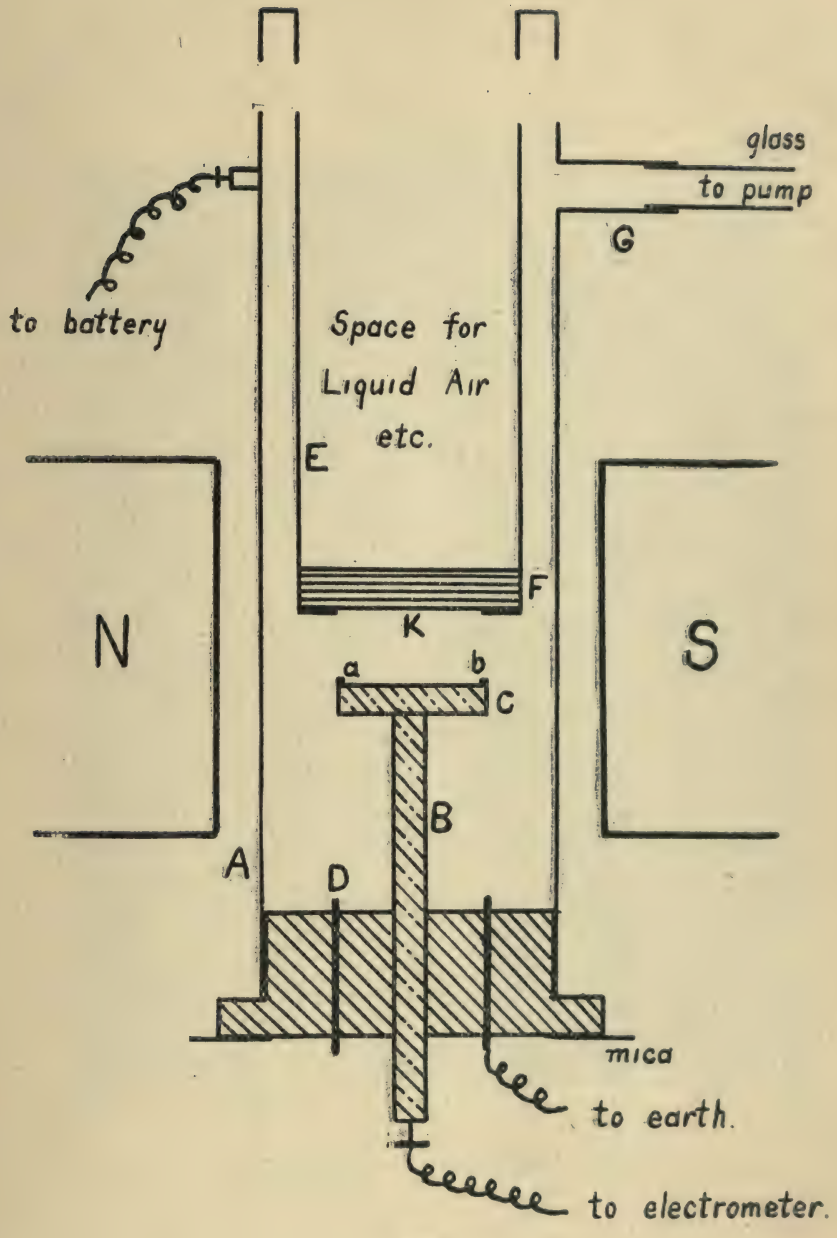

glass
to pump
G
to battery
Space for
Liquid Air
etc.
E
F
K
N
S
a
b
C
B
A
D
mica
to earth.
to electrometer.

FIG. 1.

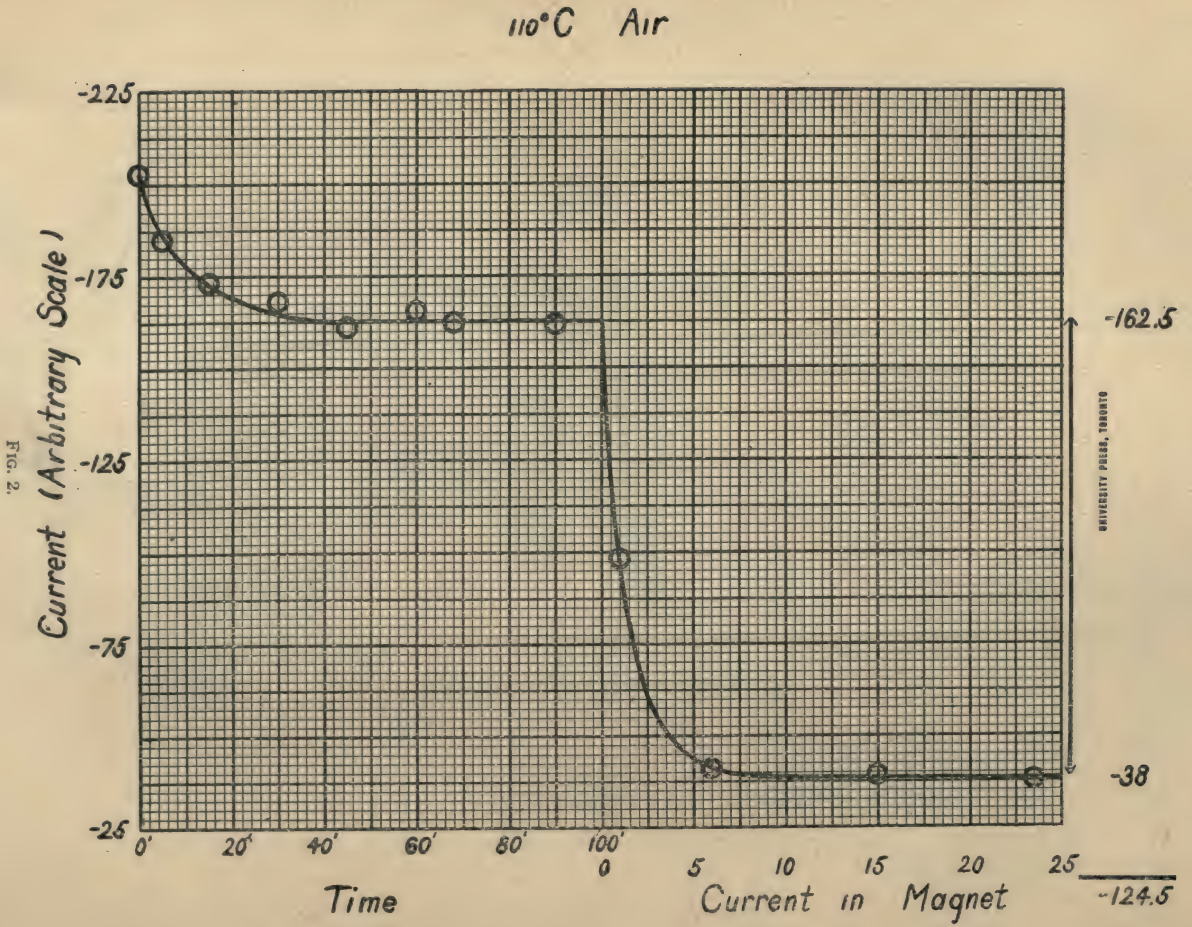

110°C Air
-225
-175
-125
-75
-25
Current (Arbitrary Scale)
0'
20'
40'
60'
80'
100'
Time
0
5
10
15
20
25
Current in Magnet
-162.5
-38
-124.5
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FIG. 2.

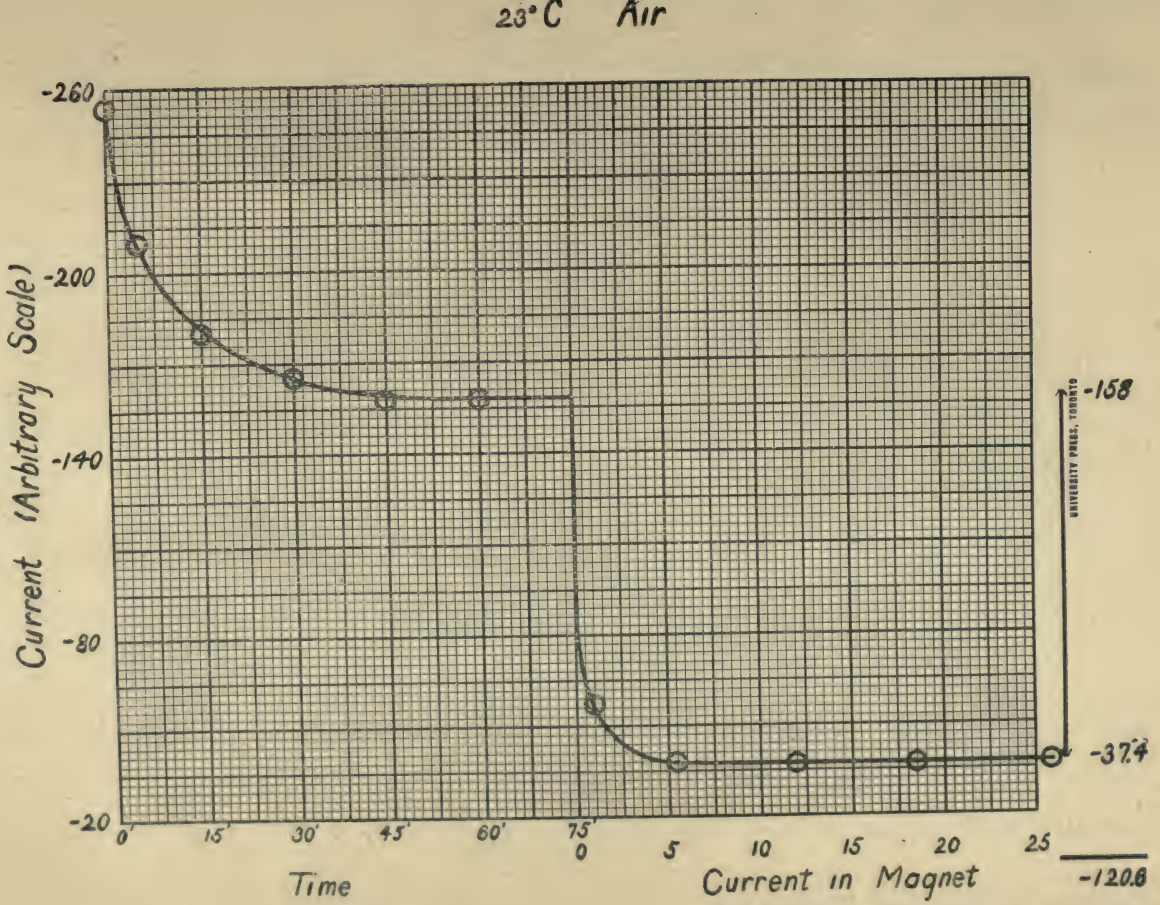
23° C Air
-260
-200
-140
-80
-20
Current (Arbitrary Scale)
0'
15'
30'
45'
60'
75'
Time
0
5
10
15
20
25
Current in Magnet
-158
-37.4
-120.8
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FIG. 3.

-78°C Air

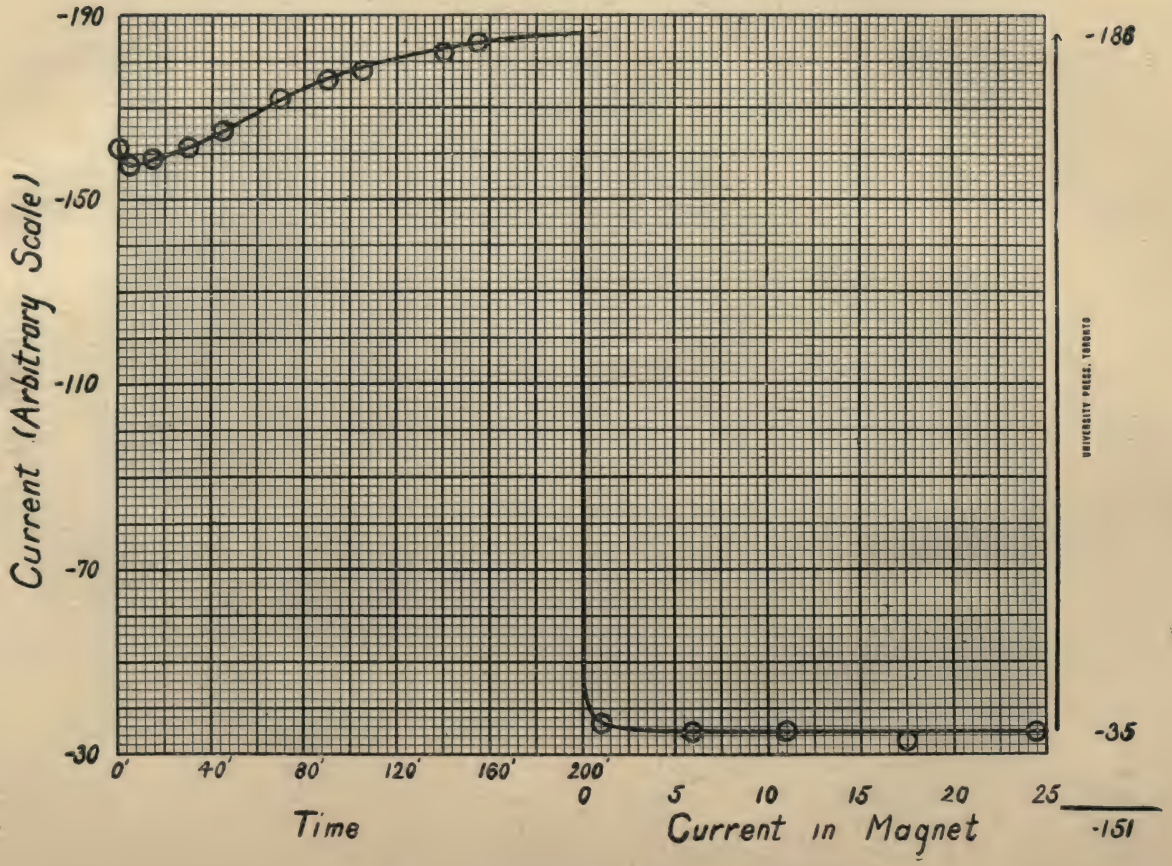


FIG. 4.

-192° C Air

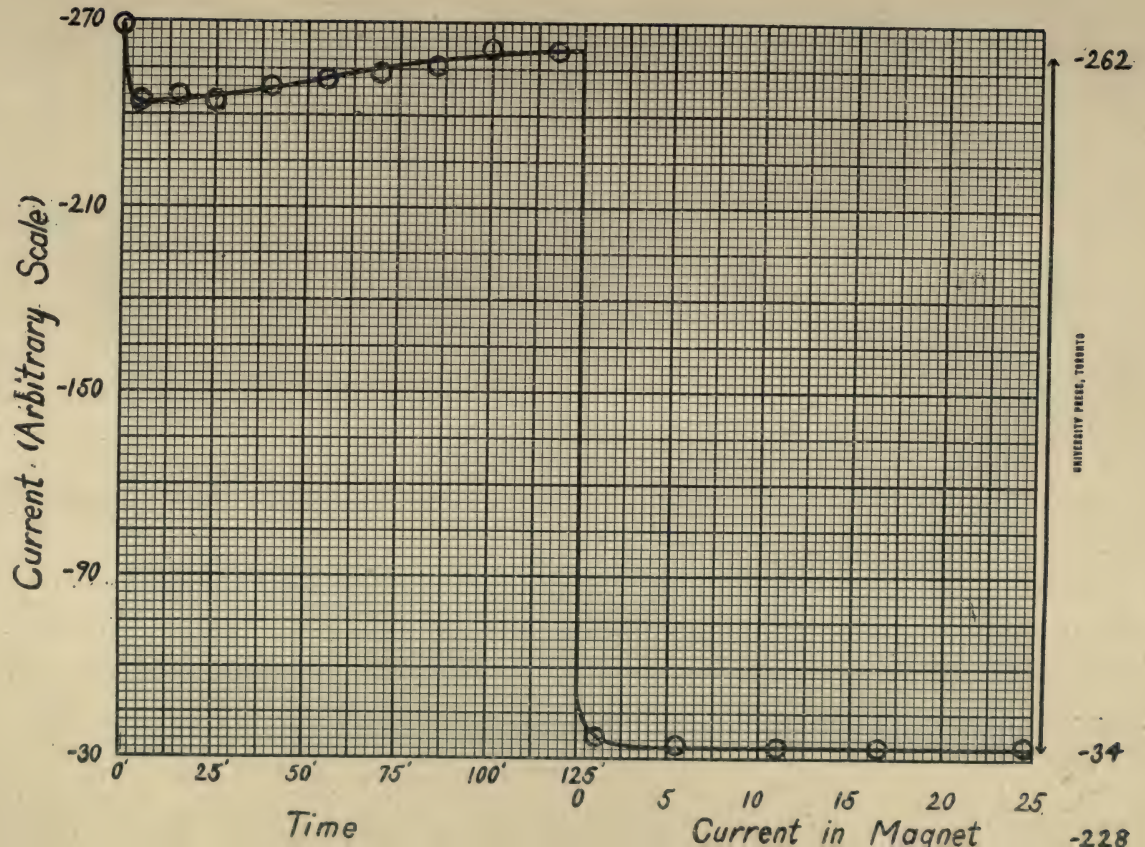


Fig. 5.

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Title The absorption of the different types of beta rays..

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